IS THERE A ROLE FOR MODERN DAY SEAPLANES IN OPEN OCEAN SEARCH AND RESCUE?

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE

by

DAVID R. BROWN, LCDR, USN
B.A., University of Wisconsin - Eau Claire, December 1980

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This thesis reviews the use of the amphibious airplane in open ocean search and rescue, and examines the applicability of a seaplane to future ocean rescue operations. The author examines the history of amphibious aircraft and why they are no longer in use by the U.S. military, including the Coast Guard. Then a comprehensive review of open ocean search and rescue missions conducted by the U.S. Coast Guard between 1993 and 1995 is used to analyze and predict whether the use of seaplanes by U.S. search and rescue agencies would save additional lives over the current methods in the open ocean environment.

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Name of Candidate: LCDR David R. Brown

Thesis Title: Is There a Role for Modern Day Seaplanes in Open Ocean Search and Rescue?

Approved by:

______________________________, Thesis Committee Chairman
CDR Robert M. Brown, M.M.A.S.

______________________________, Member
LTC Jesse D. Kreinop, B.A.

______________________________, Member, Consulting Faculty
COL Kenneth R. Garren, Ph.D.

Accepted this 6th day of June 1997 by:

______________________________, Director, Graduate Degree Programs
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ABSTRACT

IS THERE A ROLE FOR MODERN DAY SEAPLANES IN OPEN OCEAN SEARCH AND RESCUE? by LCDR David R. Brown, USN, 76 pages

This thesis reviews the use of the amphibious airplane in open ocean search and rescue and examines the applicability of a seaplane to future ocean rescue operations. The author examines the history of amphibious aircraft and examines why they are no longer in use by the U.S. military, including the Coast Guard. Then a comprehensive review of open ocean search-and-rescue missions, conducted by the U.S. Coast Guard between 1993 and 1995, is used to analyze and predict whether the use of seaplanes by U.S. search-and-rescue agencies would save additional lives over the current methods in the open ocean environment.

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CHAPTER 1

INTRODUCTION

Background

Water and aviation have been closely associated from the earliest days flight was envisioned. When pondering flight, Leonardo da Vinci suggested flying machines should be tested over water and advised on additional safety equipment. Almost from the moment the Wright brothers took to the air, a flying boat was under construction.

From its inception until the 1960s the seaplane and general aviation followed similar paths. First built in 1911, the seaplane quickly gained acceptance and use worldwide. For a time it was the even the fastest aircraft flying.[1] During World War II, seaplanes saw action all over the globe in a number of diverse roles. From attack to supply to open-ocean rescue, amphibians were truly the indispensable utility aircraft. Seaplanes performed daring sea rescues of downed aviators during World War Two, as well as in the Korean and Vietnam conflicts. In the late 1950s and early 1960s, the U.S. Navy considered the seaplane one of its primary anti-submarine warfare platforms.[2] Suddenly, however, by the late 1960s seaplanes were all but eliminated from the U.S. military aircraft inventory.

On 6 April 1996, a solo American sailor in the Pacific Ocean radioed an emergency request for immediate medical help, two hundred miles from the nearest land. No ships were anywhere in the vicinity. The ill sailor's vessel was well outside the range of any land-based rescue helicopter. The U.S. Coast Guard, with the assistance of U.S. Navy Sea Air Land Special

Operation Forces (SEALs), responded to the emergency by flying over one thousand miles with a C-130 aircraft to assist the stricken sailor. Because there was no ship in the area, the U.S. Navy SEALs parachuted into the water and tended to the very ill sailor. They then sailed the boat over two hundred miles to the nearest island that had a runway. From there the victim was flown to the nearest medical facilities.[3] The total time from the distress call to reaching medical facilities was over five days. While there is no doubt that the Coast Guard and the SEALs performed brilliantly, could an amphibious aircraft have made the rescue in five hours? Though this recent event has a happy ending, could other tragedies at sea be avoided by using modern seaplanes?

In 1996, we must recognize that even though technology has made the world seem smaller and that can cross any ocean in a matter of hours, over two-thirds of the planet is covered by water, and the oceans remain the major geographic characteristic of the earth. The unique combination of speed, range, and the ability to land on water would seem to make the seaplane a required part of any organization that conducts maritime search and rescue operations. The U.S. Coast Guard and Navy would certainly fall into that category. However, both services have stopped operating any type of amphibious aircraft altogether.

There has been no single decision to cancel amphibious aircraft from the U.S. military inventory. Instead, the cancellation of seaplane and amphibious helicopter programs evolved separately in the Navy, Air Force, and Coast Guard. The cost of operations and maintenance, the availability of maintenance support, changing roles and missions, and the evolution of the helicopter each played a part in the military service's decisions to eliminate seaplane use. The Air Force easily surrendered the maritime search and rescue mission to the Navy. Competing Naval air programs and the growth and improved ship compatibility of helicopters, gradually reduced the roles of Navy seaplanes. Budget realities, which limit airframe choices, affected the U.S. Coast Guard's options of which airframe to purchase.

Amphibious helicopters in the U.S. have met a similar fate. The cost of developing a new amphibious airframe has proven to be excessive in comparison to other military budget requirements. Additionally, the success of the Rescue Swimmer program in both the U.S. Navy and Coast Guard has reduced the amphibious helicopter requirement.[4]

Because the decisions to cancel military seaplanes were not coordinated between the services or made in the light of national requirements, was the cancellation of seaplanes a mistake? Especially in the field of search and rescue where human life is at stake, do amphibious aircraft offer a capability that needs to be supported by some national means like the military?

The seaplane by its nature is a very utilitarian aircraft. It is capable of a multitude of missions including patrol, supply and transport, as well as search and rescue. Besides the ability to land on water, seaplanes offer greater range and speeds than helicopters and generally better weight-carrying capacity. This versatility makes an amphibious aircraft particularly well suited for the maritime search and rescue role.

This thesis investigates the need for a return of the seaplane to U.S. military inventories in a search and rescue role. While it is true that the search and rescue role is being admirably carried out by a number of other platforms, this thesis examines the lack of the amphibious capabilities in the current U.S. military inventory. Could U.S. lives now being lost at sea be saved by returning amphibious aircraft, specifically a seaplane, to the inventory of the services that conduct maritime search and rescue mission?

Currently, open-ocean search and rescue operations in the U.S. are conducted by helicopters, patrol-type aircraft, and ships of various sizes. In the event of a rescue at sea, sea that is any great distance from shore, these assets have some drawbacks.

Helicopters have only fair forward speed. For a search and rescue mission one hundred miles from shore, current Coast Guard helicopter assets will take well over an hour to arrive at

the rescue location. Additionally, if the victim is not immediately found, the helicopter would have to go into a search pattern. This search pattern will also be slower due to the speed of the helicopter. Finally, current U.S. search and rescue helicopters cannot land on the water. A hoist system is used to raise the victim up to the aircraft. If the victims are incapacitated, helicopters depend on rescue swimmers who jump out and bring the victim to the rescue hoist.

Fixed-wing patrol aircraft are often involved in search and rescue operations. Patrol type of fixed-wing aircraft have good forward speed in reaching a distress location as well as speed in a search pattern. Using the previous example of one hundred miles, a patrol type of aircraft can often cover the distance in half of the time of a helicopter. However, once the rescue site is reached, fixed-wing aircraft are limited to directing other platforms to assist the victims or if they are equipped, to dropping a life raft and supplies down into the water, hoping they will be recovered by those in distress down below. If the victims are incapacitated or injured, the supplies may never be recovered.

A search and rescue ship offers excellent recovery ability and more immediate and larger first aid facilities than aircraft. Also it does not have the limited space of an aircraft. A ship's speed to the rescue site, however, will obviously be significantly slower than any aircraft. A small military ship might take five or six hours to cover a hundred-mile distance assuming it was already at sea. Even the fastest rescue boats would take close to three hours to cover the distance assuming there is favorable sea-state and weather conditions. Finally, once in the search area, a surface vessel is at a distinct disadvantage compared to an aircraft in locating a victim or vessel. The ship's speed will limit the area in which it can search in a given amount of time. Also, sensors like radar, distress emission receivers, and the human eye will perform better if they are lifted off of the surface of the ocean.

Summing up the capabilities of assets currently used for search and rescue and examining their strengths, it seems apparent that the best attributes for open-ocean search and rescue any significant distance from shore would be an asset with the speed of a patrol plane, the ability to come alongside the rescue site like a ship, as much room as possible to provide medical equipment and attention to victims, and capacity to rescue as many people as possible. A seaplane has all of these characteristics in one platform.

If the United States military services operated seaplanes in an open-ocean search and rescue role today, would additional lives be saved? Before this main question is answered, some supporting questions must also be addressed. Why was the seaplane's use discontinued in the first place? How do current production seaplanes compare with current search and rescue aviation assets in terms of speed, load capacity, and amphibious capability? Also, how successful have current search and rescue platforms been in the area of open-ocean search and rescue? I have used the answers to these questions to form a basis from which to answer the thesis question of whether or not open-ocean search and rescue forces would be more successful in saving lives with an amphibious fixed-wing aircraft at their disposal.

Significance of the Study

As the U.S. military approaches the turn of the century, declining budgets and changing roles and missions are on many military planners minds. Current economic and political realities will cause decisions regarding aircraft procurement made in the coming months and years to have greater and more lasting effects than in the years past. Additionally, these airframes will have to serve significantly longer than current assets. Therefore it is imperative that these few models have all the necessary mission capabilities. If an amphibious capability will save lives otherwise lost with current search and rescue assets, that fact should be included in the evaluation of future search and rescue airframe purchases.

Currently the U.S. Coast Guard Deep Water Mission Analysis Cell is looking twenty years into the future in order to define their airframe needs.[5] They know whatever assets they buy in the next few years must continue to meet those needs for a long time. Aircraft service life is expected to be nearly thirty years. Due to budget constraints, the Coast Guard readily admits that it will not have enough assets to completely fulfill all of its missions.

If the seaplane represents a significantly better open-ocean search and rescue asset, that fact must be established now. This study has direct relevance to those plans.

Seaplane History

In order to answer the question of whether or not the open-ocean search and rescue mission demands an amphibious capability, the first question to answer is how and why did amphibious aircraft disappear from use in the first place? A few highlights in the history of seaplanes and amphibious helicopters will help explain their current limited use and will highlight the capabilities of this type of aircraft. It also sheds some light on why seaplane commercial use has declined so dramatically since World War II.

When aviation pioneer Glen Curtiss offered to train the first naval aviator free of charge at his North Island, California, flying school in 1910, little did he know the lasting impact he would have on naval aviation. Curtiss wanted to sell his airplanes to the Navy. He thought a float under the newly invented airplane would create a product the Navy could use and would want to purchase. With Theodore Ellyson, naval aviator number one and now fellow seaplane enthusiast, Curtiss demonstrated the new "flying boat" to the Navy Department in February of 1911, and in the process became the first man to take off and land on water. Ellyson wrote to his naval superiors that he was amazed how far down into the water he could see while flying the new invention. He was sure a flyer could see a submarine beneath the surface and toss a bomb

down on it.[6] Already at this early stage in its life, the seaplane was viewed as a multipurpose functional weapon system.

Later that month, after proving the Curtiss Hydroplane could be hoisted aboard a ship, the Navy bought its first aircraft from Curtiss, the single-engine A-1. Great Britain, Germany, and Italy made similar achievements in the same year using Curtiss aircraft or models based on the Curtiss design. By the end of 1912, Great Britain was building eighty-horsepower single-engine seaplanes and Italy was launching a twin-engine monoplane. Innovations in the next few years included aerodynamic flying boat hulls, enclosed fuselages, and multistepped float design. Also of note, the first regularly scheduled airline trip took to the airways when a flying boat began scheduled flights between Tampa and St. Petersburg, Florida, in early 1914.

The British military boasted fifty-two seaplanes to only thirty-nine aeroplanes at the start of World War I. In August of 1915, a British seaplane operating in Turkish waters recorded the first ship sunk by an air-launched torpedo. Also in the same year, the converted merchant ship HMS Ark Royal saw use as the world's first seaplane carrier. It did not take long for catapults and folding-wing aircraft to develop. In Germany and Austria, seaplanes based on American and British plans appeared in 1915.

When the United States entered World War I, the U.S. Navy fielded hundreds of seaplanes, though their primary use was scouting missions for the Navy's capital ships. When the Germans began their deadly submarine effort, a new mission appeared: antisubmarine patrol. On the American east coast and all around the British Isles, seaplanes would search for U-boats on the surface. However, the limited open-ocean capability of seaplanes during this period prevented them from assisting many of the merchant ships that were attacked by German submarines.

In 1919, three U.S. Navy flying boats became the first aircraft to attempt to cross the Atlantic Ocean. Crossing from New York to Plymouth, England, by way of Newfoundland and the Azores, a Navy flying boat made the trip in fifty-four hours of actual flying time. Weather and mechanical delays on the ground, however, extended the trip to an actual crossing time of twenty-three days. The pilot at the controls of the successful aircraft was Lieutenant E. F. Stone, United States Coast Guard, the only non-Navy man in the whole endeavor.

Between the wars, the military seaplane's design continued to improve. Most notably construction materials gradually switched from wood to metal. However, due to postwar military budget cutbacks, aircraft design had to be multifunctional. The primary military mission focus for seaplanes continued to be antisubmarine warfare and scouting.

Meanwhile the new civilian aircraft industry looked for aircraft improvements that would ultimately mean profit. This translated into increased size. By 1930 German flying boats could carry over 150 passengers. By the end of the 1930s decade, large flying boats could cruise in excess of 250 miles per hour and had a range of over five thousand miles.

While much has been written about the carrier air battles later in World War II, less is known about the hundreds of seaplanes that carried on a multitude of missions including scouting for the enemy fleet, sea search and rescue, antisubmarine warfare, antiship warfare, as well as logistics, all with relatively little mention in the history books.

In anticipation of the coming war, the industrial powers of Great Britain, Japan, Germany, and the United States all were producing advanced seaplane designs. Italy, France, and the Soviet Union had amphibious aircraft in production. The war made speed, range, and lifting capability essential elements of design. Aircraft built on top of pontoons fell out of favor for aerodynamic reasons giving way to floating hull designs. Many new seaplanes also had wing floats that folded into the wing to lessen the drag and enhance the forward speed.

Throughout the U.S. war with Japan, the *Consolidated PBY Catalina* played an important role in almost every American operation. Already ten years old and considered too slow and obsolete in 1941, the number of operational PBY's in the Pacific was reduced from over fifty to less than ten after the Japanese bombed Pearl Harbor. Early in the war, however, the PBY was the only military patrol aircraft in full production. As the U.S. Navy moved to a war footing in the Pacific, the seaplane had to complete a number of challenging missions. The following year at the Battle of Midway, Catalinas were used to locate the enemy fleet and provided intelligence that would affect the outcome of the battle. They also conducted night torpedo raids and picked up carrier pilots forced to ditch in the open ocean during the battle. The value of rescuing these aviators who could live to fight another day cannot be underestimated. Finally, the PBYs sunk several hundred thousand tons of enemy shipping during the rest of the war with Japan by using new radar equipment and radar altimeters.

For the Americans, the seaplane came into its own as a dedicated search and rescue asset during this period when rescue squadrons were formed in Southeast Asia. Throughout the war with the Japan, seaplanes were regularly dispatched to find and recover downed aviators. Of special note are several perilous night search and rescue missions including the evacuation of fifty-five nurses and wounded soldiers at Corregidor before the island was overrun by the Japanese. Later PBYs would rescue downed aviators and escaped Allied prisoners off the coast of the Philippine Islands during the fighting to retake the islands.[7]

The United States was not alone in its appreciation of the capabilities of the amphibious aircraft. Great Britain, Germany, Italy, and Japan fielded a number of new seaplanes during the war. German *Heinke* and the British *Supermarine Walrus* seaplanes rescued a number of flyers from the notoriously rough English Channel during the Battle of Britain. The longer range British *Short-Sunderland* flying boats also rescued people from U-boat attacks on merchant

shipping on a regular basis out in the Atlantic Ocean. While European models saw work mostly as patrol and logistic assets, the Japanese developed a notable sea-born fighter variant of the famous *Zero*. The *Nakajima A6M2-N* was capable of speeds in excess of 430 miles per hour and had a range of over seventeen hundred kilometers.

The U.S. wartime seaplane production included a number of new models: the most successful example being the *Martin PBM - Mariner*. By VE Day over twelve hundred of this type of aircraft had rolled off the assembly line.[8] Also during this time Howard Hughes began building his giant flying boat for the U.S. government. Designed to carry seven hundred troops, the H-4 *Hercules* was made entirely of wood since other materials were being used in the war effort. After the government canceled this project, Hughes decided to finish it on his own. (The story of the one and only flight of the *Spruce Goose* is well known.) Near the end of the war, a *Martin Mars* flying boat set a world record carrying 301 U.S. Navy passengers and a crew of seven.

The civilian seaplane industry followed a similar pattern to the military aircraft during this period. In the 1930s, seaplane passenger service crossed the Atlantic and the Pacific Oceans on a daily basis. Pan American Airways pioneered transpacific and transatlantic routes using large multiengine flying boats. French flying boats crossed the Mediterranean and tied France to North Africa and South America. British Empire-class seaplanes followed a route from England to India. The growing use of passenger seaplanes continued until the war pressed many of the flying boats into military service.[9]

Worldwide, over eight thousand military and civilian seaplanes were completed between 1940 and 1946. Following all of their successes, it is no wonder that many people believed they would continue to be the preeminent mode of civilian air travel. A number of seaplane

manufacturers had postwar plans for large, amphibious, commercial aircraft. However, some not-so-subtle changes in aviation had occurred in the last six years.

During the war, the reliability and economy of land-based planes increased dramatically. Their range with a full payload grew to the point where nonstop crossings to Hawaii and across the Atlantic Ocean to England were now feasible and considered safe for passenger service. Additionally, the hundreds of long runways which had been built around the world for wartime use were now available to the civilian airways. Often these locations also had hangers and other surplus buildings were from the war and were available at a very low cost. Finally, because of aerodynamic design, the new land-based aircraft designs were generally faster than seaplanes of the day.

Commercial seaplane operations still required costly overnight stops. The flying boat market was also hurt by the fact that few of the leading aircraft manufactures of the day were willing to risk the high cost of developing new types of seaplanes on their own to compete in a dwindling civilian market. Because wartime government financial backing was no longer available to designers and manufacturers, older refurbished wartime seaplanes provided the only competition for the new land-based civilian airliners.[10] The lack of suitable civilian seaplane terminals also added to the cost and inconvenience of building a seaplane business. The cost of maintenance and operations was also a factor. Aircraft sitting in the water are more difficult to service than land-based aircraft which can be quickly rolled into a hanger under cover. The extra passenger inconvenience of boarding and disembarking from a pier all added to the difficulties faced by seaplane operators.

Since 1950, commercial passenger use of seaplanes has gradually slipped to specialized use in remote areas or islands that cannot support runways. In the United States, the best

example of this type of aircraft is the twin-engine *Grumman Albatross*. Many have been remanufactured and are in use as charter aircraft or for small island-hopping air services.

Military Seaplane Use Since the Second World War

Though technological advances have continued to improve aircraft performance, military use of the seaplane has gradually declined since the Second World War. Around the world, seaplanes generally received lower military funding priorities in dwindling postwar budgets. The Soviet Union did develop a very successful family of twin-engine amphibians. The *Beriev-6* saw service into the 1970s and was additionally exported to China. Its follow on, the *Be-12* (NATO code name MAIL) is still an excellent long-range patrol plane and is also well suited to antisubmarine warfare. It has also provided an ideal solution to the transport problems caused by the large undeveloped land mass in eastern Russia and Siberia. The production ended in the early1970s after completing over two hundred aircraft.

The British experimented with the first jet-powered flying boat in 1947. However, the program never left the experimental stage. The French and Italian postwar economies concentrated on civilian goods and services rather than military aircraft.

In the United States, the popular *Grumman Albatross* seaplane entered military service in 1949. This small twin-engine seaplane was produced in great numbers and used by all the military services. Originally designed for civilian use, this utility amphibian could carry twenty-two passengers and a crew of six. The U.S. Navy, the Coast Guard, Army Air Corps, and later the Air Force all had highly successful *Albatross* programs. It served admirably for over twenty years including some difficult combat search and rescue missions off the coast of Vietnam.

The *Martin Marlin* amphibious aircraft replaced the successful earlier model, the *Martin Mariner,* in the 1950s. This highly successful long-range antisubmarine warfare and patrol aircraft saw action up until the early days of the Vietnam War. It was to be the final mass-

produced military seaplane made in the United States. The U.S. Coast Guard and the French Navy also operated *Marlins* for a time.

During the 1950s, American designers attempted to push the limits of seaplane use. Though they saw very limited operational use, large amphibious cargo planes and tactical jet-powered seaplanes completed the test and evaluation phase of development and went into limited production during the 1950s.

Convair developed a four-engine flying boat in the early 1950s to fill the Navy's patrol missions. The project was reevaluated by the Navy in 1953 and developed into a transport aircraft called the *Tradewind*. Eleven of these aircraft were built and used in a logistical role between the U.S. and Hawaii. The *Tradewind* could carry twenty-four tons of cargo over 2,000 miles. Eleven Tradewinds were completed before production was halted by the Navy for budget considerations.

The U.S. also built an amphibious strategic bomber. The *Martin Seamaster* was developed with the cold-war idea of spreading out strategic air assets around the world to protect them. Development was plagued by accidents and only three of the planned twenty-four aircraft were ever built. By the end of the 1950s, competing budget priorities placed the damper on any further seaplane development in the United States military.

The final decisions to replace military seaplanes and their capabilities with land-based aircraft began in the 1960s. The cold war was in full vigor and the rate of change in technology was increasing at a furious pace. Antisubmarine warfare was a top priority for the U.S. Navy. On 18 January 1967, the New York Times carried a story stating the Navy planned to eliminate the use of seaplanes by 1969 in favor of the new shore-based *Lockheed P-3* antisubmarine patrol plane.

A dozen seaplane facilities at various shore installations closed their doors and the need for expensive seaplane tender ships was eliminated at a projected cost savings of over $20 million annually to the U.S. Navy. On 17 May 1967, the last operationally deployed *P-5 Marlin* from Patrol Squadron 40 made its final flight from the Philippines. The VP-40 made the transition to the *P-3* shore-based aircraft later that year. Later in 1967, the Navy officially retired the *Martin Marlin*, the last of the military mission seaplanes making way for the new *Lockheed P-3 Orion*. The *P-3* had long-range and long on-station time, which were the main requirements for the patrol mission. Export customers France and New Zealand also gave up their *Marlin* orders in favor of longer range land-based patrol planes. Thus, improvements and cost savings in new antisubmarine warfare aircraft had squeezed the seaplane out of its maritime patrol mission in the U.S. Navy and around the globe.

The Amphibious Search and rescue Helicopter

The development of the amphibious helicopter had a direct influence on the decline of the seaplane's use in search and rescue roles. The U.S. Coast Guard pioneered the use of helicopters as search and rescue vehicles in remote areas. After an early model helicopter gained worldwide attention for a daring rescue of survivors at a plane crash site in Newfoundland in 1946, a number of new military helicopter programs began.[11] The Navy placed helicopters on aircraft carriers for rescuing pilots who crashed at sea during takeoff. Helicopters replaced floatplanes on battleships and destroyers because they could takeoff without a catapult and land on the deck rather than in the water, eliminating the need for a hoist.

A number of early helicopters were fitted with floatation devices, but the first truly amphibious helicopter was introduced in 1963. The *Sikorsky Seaguard* was a true flying lifeboat. Built to U.S. Coast Guard specifications, it had a watertight hull, outrigger's sponsons, and a rescue platform that folded down and out over the water. The longer range and more

powerful *Sikorsky Pelican* joined the Coast guard fleet in 1969. It also was a fully amphibious helicopter.

But change came when the *Pelican* and *Seaguard* were replaced. The new U.S. Navy replacement helicopter was not amphibious. This forced the budget conscious Coast Guard to choose helicopters as less than optimal for the search and rescue mission. Neither of the two current Coast Guard helicopters are amphibious. The U.S. Navy is phasing out its remaining *Sikorskys*, though most sea-service helicopter pilots would prefer a machine that can land on the water.[12] In the end, search and rescue helicopters are relatively few in numbers, and owing to large development costs, must be adapted from machines primarily designed for other purposes.

The U.S. Coast Guard Seaplane Experience

The U.S. Coast Guard experience with seaplanes closely paralleled the civilian and military aviation experience. In fact, the Coast Guard was present on that fateful day in 1903 when the Wright Brothers made history. Men from the local Coast Guard Lifesaving Station provided the muscle to move the biplane from its shelter to the launch site at Kitty Hawk. In 1915, the idea of the new flying boats aiding the Coast Guard in their mission was conceived and in 1916 six Coast Guard officers were assigned to flight training at the Navy's flight school in Pensacola. The mission of early Coast Guard seaplanes was crime fighting. In 1925, the Coast Guard acquired seven seaplanes to help combat illegal rum running during the prohibition era.

Within a few years, however, the mission of these flying boats changed. A startling increase in ocean trade and new trade routes further out to sea meant that when an emergency did arise, it was frequently far off the coast. In 1928, the newly established Coast Guard aviation section developed the specification for a flying lifeboat capable of landing in the open sea and carrying out a rescue of people. In the following years, the PJ-1 *General Aviation Flying Lifeboat* was involved in numerous rescues along the eastern seaboard of the United States.

One of the unusual aspects of Coast Guard aviation is their procurement has usually come through the U.S. Navy. As early as 1920, the Coast Guard was borrowing seaplanes from the Navy for coastal patrol and search and rescue experiments. The national importance given to the new Coast Guard aviation lifesaving mission was demonstrated in 1929, when the Coast Guard was specifically given money by the U.S. Congress for seven aircraft specifically designated for the maritime search and rescue mission, instead of the usual aircraft budget acquisition methods through the Navy.

During World War II, the Coast Guard transferred into the Navy Department. Coast Guard ships and planes rescued over fifteen hundred survivors from the Atlantic and Greenland waters alone during the war.[13] Though always difficult, open-ocean landings were not unusual. Occasionally, the Coast Guard seaplane would have to taxi to shore because of the weight of the large number of people rescued.

During 1943, a Coast Guard Air Sea Rescue Squadron was formed at San Diego Naval Air Station in California. The primary reason for this squadron was the increasing number of offshore crashes by student pilots in the rapidly expanding military aircraft training program during the war. The seaplane selected to fill the mission was the *PBY Catalina*, already in production as a Navy aircraft. The program was so successful that it was incorporated around the country with an office in the Coast Guard Headquarters. By 1945, Air Sea Rescue was responsible for over 160 seaplanes and nine air stations. That year the Air Sea Rescue squadrons responded to over six hundred fifty open water rescue missions.

The Coast Guard seaplane was a coordination asset as well as a rescue vehicle. Late in the war, the submarine threat had diminished along the U.S. eastern seaboard. As merchant marine and air operations over the ocean trade routes increased worldwide, so did the need for air sea rescue forces. Regional rescue task units were organized so the Coast Guard could

coordinate rescue efforts of all the military services and all of their various assets. This highly successful system linked shore stations, seaplanes, and ships into one search and rescue network and is credited with saving over forty lives in 1944 off the northern California coast alone.[14]

Not all search and rescue missions had a happy ending. The open ocean took its toll on many seaplanes and their crews. The larger and faster seaplanes of World War II hit the water harder, often causing damage to the aircraft. Commander D. B. MacDiarmid, United States Coast Guard, is credited with developing improved open water landing techniques in 1944 and 1945. Using a *PBM Mariner* specially instrumented to measure deceleration forces, Commander MacDiarmid developed a number of new landing techniques. Instead of landing into the wind and waves, the aircraft was landed parallel to the waves accepting the resulting crosswind. This technique is still in use today. Not only have seaplanes adopted this method, but it has become the recommended procedure for the ditching of large land-based aircraft.[15]

After World War II, the Coast Guard continued to successfully operate a number of seaplanes. Simultaneously, helicopter development accelerated. Rescue by hoist was demonstrated in 1944 and the first amphibious helicopter was evaluated by the Coast Guard in 1945.[16] Initially fitted with floats, amphibious helicopters proved very versatile. The ability to land aboard smaller Coast Guard vessels was especially welcome. Helicopters found grateful support for another reason: seaplanes of the day were fine for moderate seas, but in the open ocean landing was still very challenging and often perilous. Helicopter rescue from the hover position was viewed as a way to avoid these dangerous landings in order to effect a rescue.[17]

The popular *Grumman Albatross* entered the military service in 1949. The Coast Guard took its first deliveries of the aircraft in 1951 using it to replace a number of aircraft it had been operating since the war. Eventually over seventy five of these amphibians would see rescue service in the Coast Guard. Many of these aircraft were transferred from the other services when

the Coast Guard was given the sole responsibility for all nonmilitary search and rescue missions in U.S. waters.

During the late 1960s and early 1970s, the Coast Guard began reviewing its options to replace much of its aging aircraft fleet. Interestingly enough, the 1972 requirements for a medium-range surveillance aircraft did not specify amphibious capability, nor did the 1977 requirements for a new short-range search and rescue platform. In 1977, when the last *Grumman Albatross* left the Coast Guard service, the amphibious *Sikorsky HH-3* helicopter could fulfill most of the service's amphibious needs. When the U.S. Navy replaced its version of the H-3, the Coast Guard could no longer afford the overhead of supporting an aircraft type alone. The Falcon Jet Corporation received the contract for the medium-range mission and Aerospatiale Helicopter Corporation for the short-range search and rescue mission. Neither of these aircraft can land on water.

The Coast Guard did not make a single decision to discontinue the amphibious aircraft capability. Since its budget is so limited, and without an aircraft type sponsor, such as the U.S. Navy, the Coast Guard simply cannot afford to maintain an aircraft type alone. The decisions were due in large part to the financial need to accept and buy a current production model aircraft or procure current U.S. Navy models. These independent decisions have removed all amphibious aircraft capability from the U.S. military.

Commercial Seaplane Production and Use Today

Around the world, a number of manufacturers are currently building seaplanes. The vast majority, however, are better termed "floatplanes." These aircraft are usually single-engine land planes with floats added to give them a calm-water amphibious capability. The low operational costs of these small functional aircraft make them popular worldwide. However, the poor rough

water capability of a floatplane makes its value as an open-water search and rescue tool very limited.

Undoubtedly, the largest repository of commercial seaplane experience is held at Chalks International Airlines, founded in 1919. In fact, Chalks holds claim to the title of the worlds oldest international airline in continuous commercial service. Currently, its eight Grumman amphibians service the Florida Keys and much of the Bahamas. Chalk has highly remanufactured *Grumman Mallard* and *Albatross* aircraft and offers an extensive seaplane repair service.[18]

Leading the modern industry in the manufacture of larger multipurpose twin-engine seaplanes is Canadair, a subsidiary of the Bombardier Corporation. The *CL-215* model is the most successful commercial amphibian since World War II.[19] Designed as a fire-fighting aircraft, this premier "water bomber" has seen use from Canada to Southern Europe. This multi-mission aircraft has also seen use in a military role as a patrol aircraft and supply plane. The follow-on *CL-415* model is an even more capable fire-fighting aircraft. Canadair is currently in production on orders to France and Italy. Canadair is also proposing a military version of the *CL-415* for use in special forces and search and rescue roles.

The only other companies that have recently considered building larger seaplanes are the Grumman Corporation, Dornier in Germany, and Shin Miewa in Japan. Grumman no longer is manufacturing aircraft. Dornier has reached the design test phase, but its potential customers have already selected the Canadair offering and Shin Meiwa is in limited production of a military seaplane.

The Beriev military aircraft design bureau in the former Soviet Union has proposed civilian applications for a number of its military seaplane designs, though to date little has come of these proposals.

Military Seaplane Use and Production Today

A number of military forces use seaplanes today. These countries typically have a number of coastal islands to guard like Japan, long coastlines, or large undeveloped regions like the former Soviet Union. In Brazil, World War II vintage seaplanes have made historic flights into the Amazon regions. Additionally, they are credited with much of the exploration in the area. Other successes include lifesaving and transport of medicine, people, and supplies.[20] China operates four large seaplanes modeled after the *Japanese US-1*. Though great claims have been made in the Chinese media, the capabilities of this aircraft are highly suspect. The Spanish, Greek, Thai, and Venezuelan militaries have all purchased *Canadair CL-215s*. Their use is primarily patrol along with some search and rescue.[21]

Today in the former Soviet Union, the *Beriev Be-12* still sees some limited use in coastal patrol, but overall, the approximately seventy remaining aircraft have not been properly maintained due to limited military spending.[22] The majority seem to be located in the Black Sea where the *Be-12's* limited seaworthiness does not hamper operations. The number of aircraft remaining in actual flying condition is unknown.

In the late 1980s, Beriev completed a new twin-engine amphibian called the *Be-40 Albatross*. This aircraft is capable of carrying seventy passengers over a distance of more than two thousand miles. Powered by twin jet engines, this amphibian has set an impressive number of seaplane records. Because of a lack of funding only two aircraft have been completed. The search and rescue variant of this aircraft is not expected to be funded.

Beriev also has plans for a smaller civilian version of the *Be-40* called the *A-200*. This aircraft would have passenger and fire-fighting applications and is planned to cost less than the *Canadair Cl-215* aircraft seen as the *A-200's* major competitor.[23]

Only two amphibious aircraft in on-going production today are large enough and are designed with a possible military or open-ocean use. Both are discussed at length later in this paper. The first is the *Canadair CL-415.* This sturdy twin-engine aircraft has a long-range and on-station time. The primary variant is a fire-fighting model. Canadair is currently seeking customers for this aircraft in a maritime patrol and search and rescue role.

The other current seaplane in manufacture is the *US-1* from Shin Miewa of Japan. The US-1 is operated by the Japanese Maritime Self-Defense Force. This large four engine aircraft was designed and built to land in the open ocean environment. Its unique "blown" flaps give it an unsurpassed short takeoff-and-landing (STOL) capability.

Recent Open-Water Seaplane Proposals

There have been relatively few recent large seaplane proposals put forward by the aircraft industry. In the late 1960s, the Lockheed Corporation studied the adaptability of the *C-130* aircraft into a seaplane configuration. However fully opening the integrated rear cargo door proved to be an insurmountable problem without significant airframe redesign. Conversion of the *C-5A Galaxy* was also briefly reviewed.

Probably the most recent seaplane research studies have been completed in Japan. In the 1980s, a group of Japanese aerospace companies completed an extensive study of Japanese aviation and released a report recommending a serious review of the commercial application of flying boats as a possible solution to difficulties in obtaining land for airports and solving related environmental problems.[24] In 1977, Shin Meiwa began researching a giant passenger flying boat capable of carrying twelve hundred people. However, the technology required and the sheer size and cost kept this design on the drawing board. Both Shin Miewa and the Grumman Corporation have new designs for a durable 30-to 50-passenger commuter seaplane, but neither has found a potential buyer (Grumman no longer manufactures aircraft). Most recently, in 1996, the

Lockheed Corporation is again looking at the *C-130* as a potential seaplane. Under a Navy contract, Lockheed is reviewing equipping the *C-130* with floats to be used as a U.S. Navy SEAL delivery vehicle.

Thesis Assumptions

Some basic assumptions must be made in order to examine the feasibility of returning seaplanes to active duty in the military search and rescue role.

1. The case studies examined over a three-year period in this study are representative of the kind and amount of future search and rescue scenarios in the open ocean.

2. Realities of limited funds for military research and development and procurement will limit seaplane alternatives to current production and technology.

3. When comparing seaplanes to helicopters, it is assumed that similar electronic search and rescue equipment (radar, etc.) and instrumentation can be installed in both types of aircraft.

Definition of Term

Floatplane. This is a small, usually single engine aircraft that gets its amphibious capability from floats or pontoons fixed under the fuselage.

Flying Boat. Flying is synonymous with Seaplane.

Open Ocean. For the purpose of this study, open ocean refers to water more than one hundred miles from the U.S. coastline. Generally, one hundred miles is the accepted distance out to sea where the land forms and land weather no longer affect the ocean's waves.

Seaplane. This is any one of a number of amphibious aircraft that gets its amphibious capability from a fuselage designed for buoyancy.

Search and rescue (SAR). For the purpose of this paper, search and rescue refers only to maritime missions.

Sea State. Sea State is a numerical rating from one to eight that attempts to summarize the surface conditions of an area of water. Sea-state rating is affected by wind speed, the length of time the wind has been significant, the distance the wind has been blowing over open water, wave interaction, nearby land forms, and sea swell originating elsewhere.[25] Appendix A provides a general summary and description of sea states less than five. Notably, this type of ocean rating system is falling out of favor because of the difficulty in generalizing sea-state factors into one numerically rating in a consistent fashion. Currently the Coast Guard prefers to simply call out the wind and wave height, and leave sea-state ratings to the computer models.

Limitations

In addition to the assumptions, this thesis is shaped by the following limitations:

1. The case-study approach relies on the accuracy of the reports generated by the participants in the search and rescue events.

2. Performance figures for some aircraft are available only from the manufacturer. While not the thrust of this study, their validity could influence the validity of concluding recommendations.

3. The study data is limited to data collected from search and rescue efforts by U.S. agencies in U.S. and surrounding waters.

4. This study does not specifically address the unique environment of combat search and rescue (CSAR) at sea for two reasons. First, rescue data from combat scenarios is affected by too many unique variables to apply to a review of amphibious SAR aircraft. Hostile fire, the presence of military vessels and aircraft in the area, and the extra survival equipment and skills of servicemen make their survival situations a separate area of inquiry. Second, this inquiry is particularly focused on open-ocean search and rescue missions. The majority of CSAR missions

in the Korean War and the Vietnam War were located close to shore and in somewhat protected waters, making them little use relative to this study.[26]

Delimitations

The study addresses open-ocean search and rescue events and specifically does not address Marine rescue missions close to shore or on inland waters.

The Research Approach

In order to evaluate the case for returning seaplanes to use in the search and rescue role, both capabilities and effectiveness are addressed. The discussion of the history and background of seaplanes addressed seaplane capabilities and the question of why seaplanes disappeared from military use. The development of the helicopter and longer range, land based aircraft played a part. The lack of seaplane facilities ashore and afloat and the relative inconvenience of waterborne maintenance and embarkation also played a part. The second half of the question is, Are replacement aircraft for the seaplane effective?

A definition of effectiveness can be determined from the U.S. Coast Guard mission statement. The primary goal of the Coast Guard search and rescue program is to minimize the loss of life, personal injury, and property damage in the maritime environment.[27] Thus, a major component in measuring effectiveness is in terms of lives lost.

So the question can be rephrased to: If the U.S. did have amphibious assets on its coasts, could additional lives be saved? It is the potential for lives saved that may determine the need to return seaplanes to service.

A case study approach has been selected to determine if amphibious aircraft could save additional lives over and above the current search and rescue aviation assets in place in the United States. U.S. Coast Guard cases were selected for use because they are a comprehensive

and well documented collection of search and rescue mission cases on file. Due to the mission of the Coast Guard service, it is also believed that these records will be accurate. Additionally, the Coast Guard maintains a search and rescue computer database that can be queried for cases meeting specific parameters. Searching this computerized database ensures a comprehensive review of pertinent case files.

A case study approach also permits the impact of contributing factors to be addressed. The search and rescue mission in the open ocean is affected by a number of external variables, such as wind, waves, and the distance from shore the event takes place. Case studies allow for the review of each of these factors while determining whether or not a seaplane would have made a difference in terms of lives saved in each search and rescue attempt.

A review of the actual rescue cases may also expose the impact of other factors affecting search and rescue missions, such as equipment available, the amount of time spent searching, the type of injury, the vessel involved, and the time of day. It is hoped that a case review will be more comprehensive in exposing these factors and more clearly determine whether or not the unique capabilities of a seaplane can make a difference in the outcome of some search and rescue missions.

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CHAPTER 2

LITERATURE REVIEW

Publications

Since the decisions involving the elimination of amphibious capabilities in the U.S. services have evolved over some thirty years, it is surprising to find a relatively small amount of literature directly relating to the topic. There are a fair amount of histories describing amphibious aviation. Most end in the 1960s as the helicopter becomes more popular. Many of these accounts seem to relegate seaplanes to the past, owing to new technologies or declining budgets. Popular commentary in military periodicals is very limited and also dwindles after the early 1960s. There is very little debate or comparison of helicopter and seaplane capabilities to be found.

For ease of reference these sources are divided into books, government publications, periodicals, and materials provided by manufacturers.

Books

David Oliver's Flying Boats and Amphibians Since 1945 is a summary of multiengined seaplanes produced in the modern era. Individual aircraft are described in detail and the current *use and location* of many types of seaplanes *is* given. Oliver also clearly explains his beliefs on why these aircraft have fallen into disfavor.

The American Flying Boat by Captain Richard Knott, United States Navy, is another informative history on all types of seaplanes from their inception at the turn of the century

to post-World War II designs. This detailed book also includes the current status of many aircraft, which might be helpful for anyone studying the history of seaplanes, since many amphibians have been remanufactured or remodeled extensively. Older flying boats and amphibians are still seeing use worldwide as firefighters, crop-sprayers and a host of other specialized applications.

John Killen's book A History of Marine Aviation is an excellent account of the military's development in amphibious aviation. A good deal of attention is given to the European theater in World War II.

An Illustrated History of Seaplanes and Flying Boats by Maurice Allward is a thorough seaplane history through 1980 which also contains additional detail on British seaplane development.

The Illustrated History of Seaplanes and Flying Boats by John Batchelor and Louis Casey contains detailed accounts of seaplane research and development. Seaplane exploits during the World Wars are detailed. Also contained is a history of the commercial seaplane aviation and its relationship to military seaplane aviation.

U.S. Coast Guard aircraft are nicely detailed in Arthur Pearcy's U.S. Coast Guard Aircraft Since 1916. Besides describing the ninety aircraft the Coast Guard has operated, this book also summarizes the Coast Guard's operational history, air stations, and current operations. Pearcy also authored another book titled A History of Coast Guard Aviation. Besides a historical review, this volume details a number of search and rescue missions.

The United States Coast Guard by Gene Gurney is a pictorial history of the Coast Guard. Included is early Coast Guard history, operations during war time, and Coast Guard assets. This work also details the human aspect of being a Guardsman.

Rescue at Sea by Captain John Waters, United States Coast Guard (Retired) is a very up close and personal account of the Coast Guard's search and rescue work over the last fifty years. Captain Waters served aboard ship in World War II, as the Coast Guard Search and rescue Chief in the mid-1960s and coauthored the nations first search and rescue manual. This book details, minute-by-minute in many cases, open ocean search and rescue missions around the world. Of particular interest is a chapter on seaplanes. The author concludes open ocean landings were always very difficult and seldom worth the risk. It should be noted that this book was authored before the introduction of some modern day amphibians.

Government Publications

The United States Coast Guard maintains an extensive statistical database on its search and rescue missions. Data from search and rescue missions is forwarded to United States Coast Guard (USCG) headquarters by the various Coast Guard units via search and rescue incident reports where it is entered into the Search and Rescue Management Information System (search and rescueMIS). Individual reports are held at the Coast Guard unit originating the report for a period of three years. This information is available to anyone based on the Freedom of Information Act. Each year the Coast Guard produces COMDTPUB P16107 search and rescue Statistics for that year. This document uses search and rescue mission data to evaluate the search and rescue program goals and to measure its effectiveness and efficiency. The publication also summarizes trends in the Coast Guard search and rescue program.

Research on search and rescue in a combat environment has been completed by all of the military services. The Office of Naval Research has studies on the effectiveness of maritime search and rescue during the Vietnam War. The final report titled Navy Combat Search and rescue was produced by the Biotechnology Corporation of Virginia and delivered in 1979. This

report explains the unique factors in combat search and rescue and suggests new approaches to the mission.

The Rand Corporation completed a number of studies for the U.S. government in the late 1950s and early 1960s. The military applications of seaplanes in amphibious operations, power projection, and logistics were reviewed. While the studies saw potential uses for larger and new military amphibians, each one concluded with the admission that operational and maintenance costs would be higher than land-based operations.[1]

Most scholarly papers at U.S. military graduate-level schools relating to amphibious aviation are quite old and offer little insight for current applications.

Periodicals

A clear summary of the differences between floatplanes and seaplanes can be found in "Aero-Marine Design and Flying Qualities of Floatplanes and Flying Boats" by Darrol Stinton (Aeronautical Journal, March 1987). This article is also a good primer on seaplane design.

For a complete discussion on sea states and wave forms, refer to "Sea State What?" by Captain Mel Walker (Canadian Forces Polaris, Vol. 4, No. 1, 1975).

As previously mentioned, there was very little public discussion when seaplane missions were surrendered to a combination of fixed-wing aircraft and helicopters. What little discussion there was usually followed arguments similar to those in The Future of the Seaplane by Lieutenant Kirchner, which appeared in the U.S. Naval Institute Proceedings in 1961. This article argues that seaplanes are still best suited for a number of roles including search and rescue, logistics, amphibious assault, and antisubmarine warfare. He also correctly noted that seaplane research and development was a low priority and would continue to decline.

One of the best discussions of what is required to land a seaplane in the open ocean appeared in the U.S. Navy's Proceedings in March of 1996. In "A Day in the Life of Air

Rescue," a Japanese maritime self-defense force pilot describes an open-ocean landing and rescue in heavy seas some three hundred miles from the Japanese shore.

Industry Resources

The Canadair Corporation possesses a good deal of information about seaplanes in general as well as their own products. The Grumman Corporation (now Northrop/Grumman) has probably built more amphibians than any other firm in history. Grumman still maintains a historical office with records of aircraft it produced. The Shin Meiwa Corporation, in close cooperation with the Japanese Maritime self defense force, has compiled the most recent open-ocean seaplane search and rescue statistics. At the time of this writing, neither the Chinese nor Russian firms that produce amphibians have released product information.

Other Sources of Information

The U.S. Coast Guard Internet home page contains a summary of the Coast Guard Search and Rescue mission and a listing of its aviation assets and their capabilities. There are also a number of other Internet seaplane resources dedicated to civilian seaplane and floatplane enthusiasts.

The Coast Guard Search and Rescue Program

In order to evaluate search and rescue aviation assets, it is helpful to understand the goals of a search and rescue program. The U.S. Coast Guard Search and rescue Search and Rescue Program goals will serve as a good example of what is expected in any search and rescue program.

The U.S. Coast Guard Search and Rescue Program is guided by three goals. The first is to minimize the loss of life, personal injury, and property loss in the maritime environment. The second is to minimize the search time required in a rescue through education, research and

development, regulation, and enforcement. The last is to maintain world leadership in maritime search and rescue .

These goals are supported by two important objectives. The first is to save 90 percent of the people at risk of death on waters over which the Coast Guard has search and rescue responsibility, once the Coast Guard has been notified. The second is to prevent the loss of 70 percent of the property at risk of further destruction on the water over which the Coast Guard has responsibility, also after the Coast Guard has been notified. [2]

The search and rescue program standards established to support these objectives are: (1) to initiate action within five minutes of initial notification of a distress incident, (2) to have the search and rescue unit ready to proceed within thirty minutes, and (3) to have the search and rescue unit on scene or within the search area within ninety minutes of getting underway.

The search and rescue program assumes that those lives lost before Coast Guard notification are not savable and are excluded from the effectiveness measure relating to the saving of lives. Lives lost after notification reflect the potential number of additional lives to be saved.

Search and rescue program effectiveness can then be defined as follows:

$$\text{Life Saving Program Effectiveness} = \frac{\text{Lives Saved}}{\text{Lives Saved} + \text{Lives Lost After CG Notification}}$$

Using this formula, the U.S. Coast Guard averaged slightly less than a 90 percent effectiveness rating for life saving during the 1980s and slightly better than 90 percent rating in the years after 1990.[3]

The Coast Guard search and rescue program receives over fifty thousand calls for assistance each year. Coast Guard resources respond to approximately 80 percent of these

requests, while commercial, private, and industry resources respond to the remaining 20 percent. Currently the Coast Guard averages over 4500 lives saved and 115,000 assists each year. Lives lost after Coast Guard notification average just over four hundred. Aircraft missions account for over 10 percent of the lives saved which is a significant number when one considers the annual numbers also include all inland waters and all Coast Guard small-boat rescues nationwide.[4]

Search and Rescue Capable Seaplanes

There are two amphibious aircraft in production today that could be considered for open-ocean search and rescue: the *Canadair CL-415* and the *Shin Meiwa US-1A*. While these aircraft can trace their design history back to earlier times, each incorporates rugged new designs making them significantly superior to the amphibians of the 1960s.

The US-1A was developed by the Shin Meiwa Aircraft Company as a short takeoff-and-landing (STOL) aircraft for search and rescue roles. The *US-1A* is a true amphibian and can be operated equally well from water or land. The aircraft strongly resembles a former US flying boat, the twin-engine *Martin P5M Marlin*, but has several unique features designed to provide Short Takeoff and Landing performance. The high wing has a rectangular center section mounted approximately midway along the top of the fuselage. This high placement gives the aircraft a humped profile. The outer-wing panels are double tapered and have leading-edge slats as well as trailing-edge flaps and powered ailerons.

The dorsal hump also covers the 1,400 horsepower gas turbine engine that generates the air for the Boundary Layer Control (BLC) system that is the source of the *US-1s'* STOL performance. The BLC air is blown over the inside section trailing-edge flaps which can be deflected to eighty degrees. Outer-edge trailing flaps can be deflected to sixty degrees to take advantage of the propeller slipstream. This system gives the *US-1* very slow landing and takeoff-speed capability.

The aircraft has a large T-tail carried high on top of the fuselage. Both the large rudder and the elevators are also blown by the BLC system for slow-speed performance. Horizontal tailplanes on top of the rudder have leading-edge slats and full-span elevators. The US-1 has an automatic flight control system and two independent hydraulic systems.

Four 3,500-horsepower turboprop engines drive the aircraft. It has a very hydrodynamically efficient Deep-Vee hull and a long length-to-beam ratio. The hull's single-step design and spray skirt add to the quick planning ability of the craft. This design permits landings and takeoffs in high sea states with waves running eight-to-thirteen-feet high. The flight deck is set high above the radome for good visibility. The aircraft has fixed strut, braced wing floats and retractable tricycle landing gear. Its overall length and wingspan are just under 110 feet. The aircraft mission radius is over one thousand miles.

US-1 search and rescue aircraft carry a six-man motorized inflatable dinghy that is launched and recovered from a ramp deployed from a rear sliding door.

The second production seaplane capable of open-ocean operation is the Canadair *CL-415*. The aircraft is an improved version of the *Canadair CL-215*. In its primary configuration, the *CL-415* is designed to scoop up 13,500 pounds of water for fire fighting. The aircraft also comes in a maritime patrol version with room for passengers, litters, or mission equipment. The *CL-415* has a mission radius of approximately six hundred miles.

The *CL-415* has a high-mounted wing, bow, and chine spray suppressors and a hydrodynamically efficient hull. Elevators are mounted high on the tail. The aircraft has retractable landing gear and so is also a true amphibian. Two 2,380-horsepower turboprop engines are mounted on the wings. Propellers are fully reversible giving the aircraft excellent handling capability in the water. All flight control surfaces are hydraulically driven. The *CL-415* design permits landing in water with wave heights of over six feet.

Current Amphibious Helicopter Summary

The production of fully amphibious helicopters has all but ceased worldwide. Still in service are the *MI-14 Haze*, the *Aerospatiale Super Frelon*, and the *Sikorsky H-3*. These aircraft have fully amphibious boat hulls and are excellent search and rescue craft with ranges in excess of 250 miles. The Chinese are producing a variant of the *Super Frelon* in limited numbers.

Wing-In-Ground-Effect Craft

Another type of amphibious aircraft that has not yet been fully developed use wing-in-ground-effect (WIG) technology. WIG vehicles take advantage of an additional lift provided by a cushion of dense air trapped between a large wing and the surface of the water. The drag on an aircraft due to lift is considerably reduced if the altitude of the aircraft is similar to the length (chord) of the wing. This technology potentially offers range and fuel economy even better than standard flight.

Before the dissolution of the Soviet Union, Russian design bureaus had designed, tested, and built large amphibious WIG craft for use on the Caspian Sea. Since most early technical problems have been overcome, the technology is now for sale, but due to a lack of funds development has slowed considerably. This technology holds great promise for search and rescue but has not been developed.

During the second week in January 1997, the newspaper China Today carried the announcement by the Chinese government that a sixteen-passenger WIG aircraft was in production and due to begin operations this year. The article also stated a much larger craft is in development. While it is difficult to judge the validity of the Chinese claims, it is very likely that this is exported Russian technology.

Current Amphibious Aircraft Search and Rescue Operations

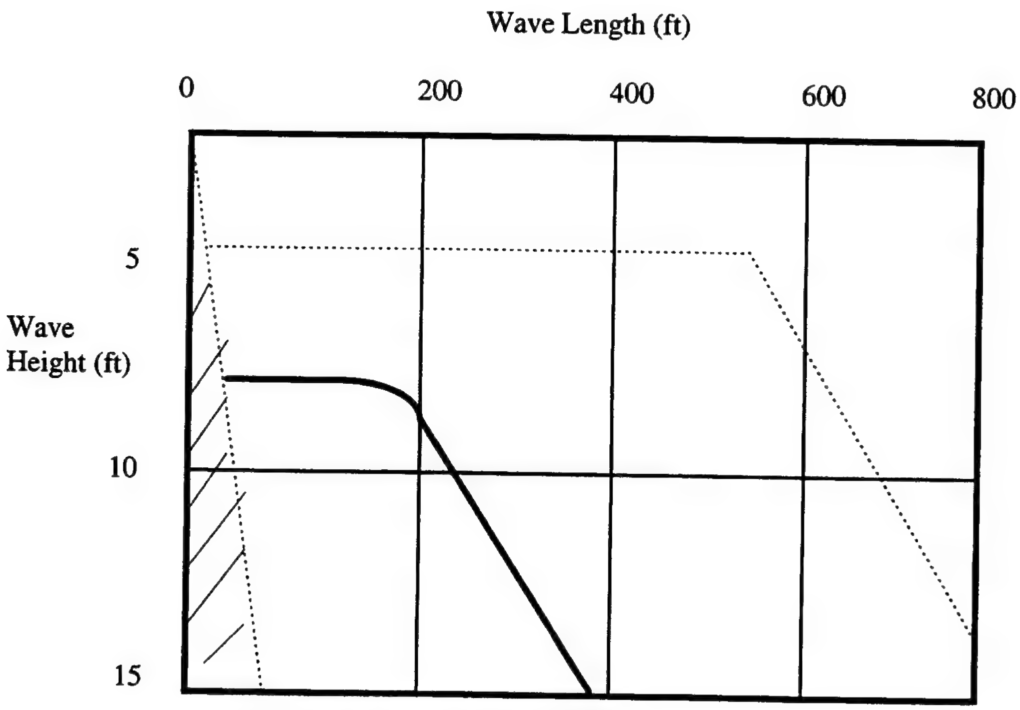
The best example of a current seaplane search and rescue operation comes from the Japanese Maritime Self-Defense Force (JMSDF). They are operating ten *Shin Meiwa US-1As* for open-ocean search and rescue as well as support or evacuation of victims from remote islands which do not have runways. Widely regarded as the best and most advanced seaplane ever built, the *US-1A* has been in service since 1976. In Japan, helicopters perform the search and rescue mission close to shore while the *US-1A* is tasked with rescues farther out to sea. Japanese figures show the *US-1As* from the JMSDF have completed an average of ten-to-fifteen life saving rescues each year since they have been put into service.[5] A number of rescues have been accomplished more than six hundred miles off the shores of Japan.

However, seaplanes do have their limits. Seaworthiness limitations are a major factor in operation of the *US-1A*. The operational capability areas of the *US-1A* are summarized in figure 1.

This figure indicates that in order for the *US-1A* to land in ten-foot seas, the wave length must be approximately two hundred fifty feet in length, not unusual in the open ocean. Landing capability is also affected by a number of other factors including aircraft weight at landing and the amount of head wind.

Studies were conducted by the JMSDF and Shin Meiwa to match the *US-1As'* performance capability against the characteristics of the ocean waters surrounding Japan. Sea states and wave periods were measured and averaged in the Sea of Japan and the Northern Pacific. These studies indicated that the *US-1A* would be operable 77 percent of the time. The other 23 percent of the time sea states would be in excess of the aircraft's capability to land on the ocean if required. In actual operations, the *US-1A* has actually been successful in 87 percent of its rescue attempts.[6]

The Japanese Maritime Self-Defense Force pilots who fly the *US-1A* also undoubtedly possess the largest amount of experience available regarding open-ocean seaplane landing. Personal accounts attest to the challenges of landing a large seaplane in the open ocean as well as maneuvering the aircraft once on the water.[7]



——— US-1 Landing and take-off wave height capability

........................Conventional seaplane landing and take-off wave height Capability.

Figure 1.

Comparison of All Current Search and Rescue Assets

Appendix B is a general comparative summary of aviation as well as ship search and rescue assets currently used in the United States. All range and speed data provided are approximate.

[1]Rand Corporation Some Logistical and Cost Considerations in Military Operation of Water Based Aircraft, (Rand Corporation, 1955 declassified).

[2]SAR Statistics 1993, United States Coast Guard, COMDTPUB P16107.6, 1994.

[3]SAR Statistics 1993, United States Coast Guard, COMDTPUB P16107.6, 1994.

[4]SAR Statistics 1993, United States Coast Guard, COMDTPUB P16107.6. 1994.

[5]Yushi Tanaka, Search and rescue Amphibious Aircraft in Japan (Shin Meiwa Industry Co. Ltd., Kobe, Japan. 1988).

[6]Ibid.

[7]Shoki Inoue, "A Day in the Life of Air Rescue," USNI Proceedings (March 1995): 95.

CHAPTER 3

RESEARCH METHODOLOGY

The Research Plan

The plan to evaluate the case for returning seaplanes to use in the search-and-rescue role consists of two parts. The first part reviews the historical use and application of the seaplane. The purpose of this part is to examine past search-and-rescue successes and to determine the capabilities of the platform as a search-and-rescue tool. A historical perspective also highlights some of the strengths and weaknesses of this type of aircraft.

The second half of the research reviews modern day search-and-rescue case studies and looks for the applicability of the modern day seaplane. A case study approach was selected since seaplane capabilities have improved dramatically in recent years, and there is little or no research available on the possible effectiveness of a search and rescue seaplane in U.S. waters today.

In order for a seaplane to be effective in the United States search and rescue effort, it must enhance the current search-and-rescue force: namely the U.S. Coast Guard. Specifically, it must add the ability to save lives where and when they would otherwise be lost using current search-and-rescue methods. By looking at cases where lives were lost at sea during a Coast Guard search-and-rescue effort and theoretically, inserting a seaplane into the scenario, it is possible to evaluate whether or not additional lives might be saved in similar, future situations. Deliberately, the cases selected were those where a seaplane might offer some mission capabilities not found in other search and rescue platforms. By reviewing cases where lives were lost at sea more than one hundred miles from shore, the potential of the seaplane might be

highlighted. The advantage to this method is comprehensiveness. Since it is reasonable (and possible) to examine every case where Coast Guard assets were involved in a search and rescue over one hundred miles at sea and lives were lost, a "big picture" assessment can be made.

The distance of one hundred miles from shore was selected for two reasons. Since a seaplane operates at approximately twice the forward airspeed of a helicopter, one hundred miles approximates the point where time of flight to a location becomes significant. After one hundred miles, the difference in time of flight between aircraft types is more than twenty minutes. One hundred miles also approximates the distance from shore where the sea state is independent of nearby land forms, so a more accurate assessment of open-ocean performance can be made.

Obtaining the search and rescue case information is possible because of the record-keeping system of the U.S. Coast Guard. Detailed accounts of search and rescue missions are kept for three years at the originating Coast Guard station before they are sent to the National Archives in Washington, D.C. These reports called situation reports (SITREPS) also provide the raw data for the annual search and rescue statistical summaries produced by the Coast Guard. Using the U.S. Coast Guard search and rescue database computer, thirty-nine cases were identified in the last three years where Coast Guard aviation participated in a search and rescue effort more than one hundred miles at sea and where at least one life was lost after Coast Guard notification. The complete description of the events in the form of the original SITREP was obtained from the Coast Guard station involved in each of the forty-three search and rescue missions. Appendix C contains a generic SITREP reporting format.

Speed, time to the rescue, time on station, relative cargo capacity, and an amphibious capability are the advantages a seaplane brings to a maritime search and rescue. Through examination of the original Coast Guard search and rescue SITREPS, an evaluation of how these factors played into the resultant loss of life can be made. The future value of a search and rescue

seaplane can then be established by simply plugging a seaplane into the cases and determining if the results would have been different.

CHAPTER 4

ANALYSIS

Introduction

The case studies[1] evaluated here represent the thirty-nine events recorded by the U.S. Coast Guard in which a life was lost more than 100 miles off the coastline between 1993 and 1995 after the Coast Guard was notified of the emergency. Undoubtedly, there are more cases that fit this description that were not recorded or reported, but these are the events the Coast Guard participated in, making records much more accurate and informative.

Speed, time to the rescue site, time on station, relative cargo capacity, and an amphibious capability are the advantages a seaplane brings to a maritime search and rescue. Other factors affecting an amphibious rescue are weather and sea state, time of day, physical condition of and injuries to the victim, and the type of vessel involved. Each of the cases is evaluated using these factors. The type of rescue effort mounted is briefly described and finally the question is posed, "Would a seaplane have made any difference in the outcome of this event?"

The cases are arranged by year within each Coast Guard reporting district in order to expose any case similarities arising from ocean characteristics or geography. Some cases involve multiple Coast Guard units from neighboring districts. To avoid confusion and duplication, these cases are only listed in the district whose assets did the majority of the search and rescue effort.

While the actual case numbers, names of vessels, and names of people involved in these rescue attempts are available to virtually anyone via the Freedom of Information Act, these details were deemed not important to the research and are omitted.

In some of the cases the loss of life is immediate or the situation is such that little can be gained from reviewing the case. A brief description of these types of cases is still included for completeness. Finally, anywhere the Coast Guard files are incomplete or the original record of the event is missing, that fact is noted and whatever information is available from the national statistical summary is given.

Case Studies

Seventh District

The Coast Guard's Seventh District has responsibilities in both the Atlantic and Gulf of Mexico and has headquarters in Miami, Florida. Six cases matching the 100-mile and loss-of-life profile were found in Seventh District files.

The first case occurred in January 1993. A 150-foot Colombian vessel carrying seven people and 600 tons of sand capsized 200 miles south of Miami when the load it was carrying shifted. Rescue authorities diverted a nearby U.S. Navy ship and a P-3 patrol aircraft after the mishap was confirmed by a second source. The Navy ship launched its rescue helicopter as soon as it was in range of the sinking vessel. The patrol aircraft was on the scene in one hour, the ship's helicopter in four and one-half hours and the ship arrived almost eight hours later, just before darkness fell. Three people were rescued by the helicopter, and a fourth found floating dead in his lifejacket. The other three people never made it off the sinking vessel or drowned and were not found.

The weather was reported to be good with four-foot seas, light winds, and visibility in excess of ten miles. Due to the incapacitation of the survivors, the helicopter deployed its rescue swimmer twice within thirty minutes to aid in hoisting victims.

An analysis of this case shows a seaplane launched from the Coast Guard station in Puerto Rico would have been on station in less than two hours, potentially rescuing the seaman

found dead in his lifejacket. Additionally, the danger of an overworked rescue swimmer would be reduced or eliminated. The search for the three missing crew members would have started at least two hours earlier. Time was especially critical in this case as rescue assets were required to set out on a second concurrent distress call as soon as it was determined the chances of finding any more victims was small.

The next case occurred in September 1993. A U.S. seaman apparently electrocuted himself while welding on the boiler of a 500-foot tanker vessel located 250 miles south of Miami. Crew members began life support immediately. Coast Guard rescue coordinators determined that the nearest help was a Navy helicopter over two hours away. However, there was no place for the helicopter to land. The Coast Guard flight surgeon recommended discontinuing the first aid cardio-pulmonary resuscitation (CPR) and any rescue attempt based on the remote chance of survival and the length of time until medical personnel would arrive.

It is unknown whether the victim had any chance of survival in this case. However, a seaplane could have left Miami and been floating along side the tanker in one hour, unlike the helicopter which had no place to land. Additionally, it could have easily carried additional emergency medical personnel and medical equipment for this situation.

The third case from the Seventh District involves a U.S. citizen who fell overboard from a commercial fishing vessel in January 1994. He apparently drowned immediately. The vessel and crew were able to return and grab hold of the victim, but were unable to bring him aboard because of his weight. A Coast Guard helicopter brought the body back to Clearwater, Florida, where he was pronounced dead on arrival. Only a personal floatation device would have changed the outcome of this case.

The fourth case took place over 200 miles west of Miami in January of 1995. A 650-foot bulk cargo vessel radioed for Coast Guard help for one of the Polish crewmen apparently suffering a heart attack. The ships emergency lifesaver administered nitroglycerin and began CPR. Because of the distance, the rescue helicopter took two hours to arrive from Clearwater, Florida. The victim was then hoisted up into the helicopter where CPR was continued for the two-hour trip back to the hospital where he was pronounced dead.

In this situation, a seaplane might have delivered a doctor and medical equipment to the ship in half of the time it took the helicopter to arrive. Also the procedure of hoisting of the victim, temporarily stopping the CPR, could have been eliminated. Whether this action affected the eventual death is unknown.

The next case occurred in April 1995. A 180-foot vessel from Belize sank 200 miles north of Venezuela when its cargo of cement shifted. Four of the eight Cuban crew climbed into a raft and drifted for five days before they were picked up by a passing ship. The other four crew were thought to be wearing life jackets and to be in the ship's ten-foot utility boat. The Coast Guard received a ship overdue report the day before the survivors were picked up and commenced searching after the rescue vessel reported picking up survivors. The C-130 and P-3 patrol aircraft searched for three days without finding any evidence of the other crew members.

During the search the wind increased to thirty knots and sea swells reached ten feet. It seems little else could be done in this case. The patrol aircraft carried out a large, relatively fast search for the missing crew. Had the crew been located, they would have been without food or water for nearly a week. If a fixed-wing aircraft would have spotted additional survivors, their rescue would have been delayed an additional four hours while a Coast Guard helicopter sortied out to retrieve them, assuming there was a helicopter within range.

The sixth case in the Coast Guard Seventh District also takes place in April 1995. An 800-foot container vessel reported a Russian crewman overboard 100 miles off the coast of St. Augustine, Florida. The vessel reversed course and began searching while the Coast Guard launched a fixed-wing aircraft to assist in the search. Another cargo vessel also assisted in the search. The search was terminated at the end of the day after it was confirmed that the victim was not wearing any personal floatation device. Suicide was a strong possibility in this case.

A seaplane would not have altered the search time in this case. However, if the man was located in the water, the potential exists for a seaplane to reduce the time to rescue by as much as two hours. It should be noted that Coast Guard fixed-wing assets searching for this man were prepared to deploy a raft to him if he were spotted.

Eighth District

The Eighth Coast Guard District has its headquarters in New Orleans and is responsible for approximately three-quarters of the Gulf of Mexico. Two search-and-rescue events meet the case study search criteria posed between 1993 and 1995.

Case number seven takes place over 100 miles south of New Orleans. An American man fell overboard a seventy-five-foot shrimp boat in rough seas in the middle of the night. He was not wearing a life jacket. The crew threw a life ring to the man, but they were not sure if he was able to retrieve it. The Coast Guard launched a helicopter, a fixed-wing aircraft, and a cutter to conduct the search. Eight other fishing vessels and two supply vessels also joined in as the search progressed. Though the helicopter was first on the scene, the flight out to the location of the man overboard had consumed most of its fuel, so it was only able to search for one-half hour before returning for fuel. The helicopter returned to the location some three hours later after the transit back ashore, refueling, and the return flight. Again its search time was very limited. The helicopter was not able to return a third time due to crew fatigue.

Though thunderstorms frustrated much of the airborne search effort, as many as twelve surface vessels at any one time were involved in the search effort. The Coast Guard Cutter arrived on scene seven and one-half hours after the initial call and directed much of the search. The search was suspended at the end of the following day due to bad weather, cold water temperatures, and the thoroughness of the surface search.

The limited search range and search time of a helicopter is highlighted in this case. In two flights and over six hours of flight time, the helicopter crew was on station searching for little more than one hour. The weather proved to be a wildcard that allowed only the helicopter, which came from a different home base, to search during the first few hours the man was overboard. The cold water (57 degrees according to the report) meant the man had to be found quickly. A seaplane would have arrived sooner and would have been able to stay searching significantly longer than the helicopter in this case. However, much of the early search was conducted at night. The slower search speed of the helicopter has to be considered a positive feature, especially in darkness.

The eighth case occurred in December of 1994 on a seventy-five-foot shrimp boat 100 miles southeast of Galveston, Texas. An American collapsed of an apparent heart attack. The boat's crew called for help and began administering CPR. The rescue helicopter arrived one-and one-half hours later. The victim was transferred to the helicopter and arrived at the hospital in Galveston a total of two-and-one-half hours after he collapsed.

In this instance time and the lack of immediate medical facilities are major factors. A seaplane might have delivered the patient to the hospital in half of the time or perhaps delivered a physician and medical equipment to the scene in one-fourth the time it took to get the victim to the hospital.

Thirteenth District

The Thirteenth Coast Guard District has its headquarters in Seattle, Washington and is responsible for the coastal waters of Washington and Oregon. Three cases meet the search criteria.

Case number nine occurred in July 1993 approximately 250 miles off the coast of Oregon. A 600-foot Japanese freighter heading for Portland reported a Filipino National crewman overboard in the middle of the night. The man, a cook, had been missing for at least two-and-one-half hours by the time the crew completed searching the ship. When he could not be located, the Coast Guard was notified. The weather at the time of the man overboard was poor: seas were ten feet, the wind was in excess of thirty knots, and the water temperature was sixty-four degrees. The ship did not reverse course and look for the missing man.

Due to the distance to the rescue area and the lack of a refueling site, an airborne search and rescue effort was not launched. Other contributing factors include the length of time the man had been missing, the weather, and the water temperature. Because of the poor location data on the missing man and the length of time he was in the water, his chances for survival were obviously slim. Even if a search and rescue was to be attempted, the rescue site was too far out to sea for search and rescue helicopters. A seaplane would have been able to fly this distance, search, and land for rescue if required. This type of rescue would no doubt challenge the limits of current seaplane landing capabilities.

Case ten occurred in February 1994 when a request for help was received from a 500-foot Greek freighter. A Greek woman on-board was suffering from severe vaginal bleeding. Fearing for the woman's life, the search and rescue medical advisor recommended a rescue. However, the ship was located over 300 miles off the Oregon coast. The weather at the time of

the incident was relatively calm: four-foot seas, light winds, and generally a low overcast ceiling.

Due to the distance and the perceived severity of the case, the search and rescue coordinator asked the U.S. Air Force Air Rescue Squadron (AARS) from Portland if they could provide assistance. The AARS accepted the mission and launched two Pave Hawk helicopters and two C-130 tankers to refuel the helicopters enroute. Coast Guard fixed-wing aircraft provided an intermediate communications link during the rescue. The helicopters hoisted the woman aboard in a rescue basket and flew her to a Portland hospital. Some hours later the woman had a miscarriage. A total of twenty hours elapsed from the time of the distress call to the time the woman reached medical help.

No doubt the AARS performed admirably throughout the mission. However, it does seem that in this case five aircraft and a twenty-hour rescue time could easily be replaced with one seaplane and a significantly shorter rescue time.

Case eleven is from March 1995. The Pakistani captain of a 600-foot freighter had been sick with an unknown illness for a number of days while crossing the Pacific to the west coast of the U.S. Two days and 150 miles off the coast of Washington, the acting master of the vessel discovered the captain in his bed with no vital signs. The ship radioed for help, but was frustrated by weak communications. With the help of a Coast Guard aircraft on a training mission, positive radio contact was made two hours later.

When the crew reported that the captain had signs of stiffening in his body, the acting flight surgeon determined that this was a coroner's case. Analysis of this matter seems to show that no matter what assets were employed, the outcome would be the same. Based on the rigor mortis, the captain was apparently already dead by the time the first radio contact was made with rescue assets.

Atlantic Area

The Atlantic Area comprises the First and Fifth Districts and has its headquarters in Virginia. It is responsible for coastal waters from Maine to Georgia, as well as waters past Bermuda and south towards the coast of South America. Fourteen cases meet the case study search criteria in the Atlantic area.

Case number twelve involves an overdue thirty-two-foot pleasure sailboat transiting from North Carolina to Bermuda in May of 1993. The craft was reported missing the third day it was late into port. The single sailor was apparently very inexperienced, had abandoned his crossing attempt, and began to return to the U.S. coast without notifying marine traffic authorities. A Coast Guard C-130 aircraft located the vessel returning to port the next day after it was reported overdue.

The death in this case occurs later and is unrelated to the search and rescue effort. A seaplane search would have yielded similar results as any fixed wing aircraft.

Case thirteen revolves around a Russian vessel's master who suffered a heart attack in September of 1993. The 700-foot vessel was located over 400 miles northeast of Puerto Rico, enroute to England at the time of the incident. A helicopter hoist was offered to the ship, but because of the distances involved, the ship would have to sail 200 miles back south to bring it in range of the nearest search and rescue helicopter. The option of specially trained medics parachuting into the water alongside the vessel was also considered.

However, the weather proved to be the deciding factor in this case. A tropical depression was forming near the vessel and increasing sea states, and thunderstorms were also predicted. The Russian crew performed CPR for two hours before determining that it was futile to continue CPR for twenty-four hours while the vessel sailed into the search and rescue helicopter's range.

In this case a seaplane may have been able to immediately fly out to the vessel with medical help on-board. Potentially it could have arrived within the two hours the crew was performing CPR. At the time the seas were six to eight feet with winds fifteen to twenty knots with the tropical depression predicted to arrive in less than eight hours. While the sea state is within the capabilities of a modern seaplane, the small time window before the storm hit would have to be gravely considered.

Case fourteen is another heart attack victim in the middle of the Atlantic Ocean during 1993. The New York Rescue Center received a call for help stating that the master of an American vessel was having difficulty breathing. Fifteen minutes later a second call was made stating that the seaman had died. Due to the distant location of the vessel and the decision of the crew not to perform CPR, no rescue attempt was made. It is unlikely that the availability of a seaplane would have made any difference in this case.

Case fifteen occurs when a forty-five-foot fishing boat leaves the U.S. bound for Honduras, but is subsequently lost at sea. The Honduran captain of the vessel had apparently purchased the boat, stripped out most of the interior, and was moving it to Honduras to be used as a cargo vessel. The third day the vessel was overdue the Coast Guard began searching south of the vessel's last known position. Two Coast Guard fixed-wing aircraft and a number of private vessels participated in the search, but the vessel was never seen again.

Both of the Coast Guard fixed-wing aircraft were able to search for long periods of time and officials felt there was a high probability that this vessel would not be found. It is unlikely a seaplane would have made any difference in the outcome of this incident.

Case sixteen is a sixty-five-foot fishing vessel that capsized with four Americans on board 130 miles off the coast of North Carolina. Good weather was reported with seas only three to four feet. The vessel's safety equipment had sent out an immediate emergency signal as soon

as the boat tipped over, so the U.S. Coast Guard was able to launch a C-130 aircraft and a helicopter almost immediately. After two hours of searching, the aircraft reported finding some seat cushions and a raft. The helicopter deployed its rescue swimmer, but found nothing in the raft. Coast Guard aircraft continued to search for two days. Unfortunately nothing more was found from the fishing vessel. Of note, helicopter assets were able to operate from a U.S. Navy ship that happened to be in the area, greatly increasing their search time and radius.

In this instance, a seaplane may have reached the search and rescue area in approximately one-half of the time it took for the helicopter to arrive. Also the time required to search any given area would be less. Officials believed the crew never made it into the life raft, so time to the rescue would be critical. While the report does not specify the water temperature, it can be assumed that a man in the water at this location and time of year would succumb to the cold and drown in less than two hours.

Case number seventeen occurred in January 1994. A Dutch bulk cargo ship enroute from Canada to Holland sunk 700 miles east of Nova Scotia. The estimated weather at the time of the accident was ferocious with winds over fifty miles per hour and with waves exceeding thirty-five feet tall. The ships emergency beacon began transmitting at the time of the sinking and the first search and rescue aircraft, a C-130 arrived five hours later. No sign of any of the thirty-four people on board has ever found.

A seaplane would not have added any capability to this search and rescue mission. In fact, the C-130 aircraft is probably more air worthy in this type of weather. Certainly no water landing would have been attempted.

The next case, number eighteen, also occurs in the middle of the Atlantic Ocean. A freighter from the Netherlands reported a man overboard. The chief mate had apparently gone up on deck in bad weather without any survival gear and was lost overboard. Due to the sixty

degree water temperature, the length of time before search and rescue assets would arrive, the onset of night fall, and the fact that the man was not wearing any survival gear, rescue coordinators decided not to launch any rescue attempt. It is unlikely any type of search and rescue aircraft could have helped this man.

Case number nineteen occurs over 300 miles northeast of the Venezuela. In March 1994, a Cypriot freighter reported one of its crewmen, an Indian, had fallen twenty-five feet off a crane onto the steel deck below. The ship reported that the man was bleeding from a head wound and from his ear and that they suspected other broken bones as well. An immediate helicopter rescue was requested. However, due to their location, the nearest search and rescue helicopter (from Puerto Rico) was well out of range. The ship was advised to proceed at best speed toward the South American coast where a rescue helicopter was ready to launch as soon as they were in range. Unfortunately, before the ship reached the effective range of the South American rescue helicopter, the man died. All attempts at resuscitation were unsuccessful.

In this case, it is possible a seaplane might have been able to reach the vessel with medical help on-board before he died. However, due to the severity of the wounds, it is unclear if any medical assistance would have prevented this man's death.

Case twenty is a man overboard in January 1994. A freighter located approximately 150 miles off the coast of South Carolina reported a crewman from Singapore was washed overboard in heavy weather, falling some thirty feet down into the 68-degree water. The wind was estimated at thirty miles per hour and the waves at twenty-feet tall. The man was not wearing any personal flotation gear. The vessel's crew threw a life ring and a smoke markers into the water and then turned the ship to attempt to relocate the victim. Concurrently, the vessel radioed the Coast Guard for help, and a second vessel steaming nearby joined in the search.

While the mishap location was within range of coastal search and rescue helicopters, a decision not to launch was made based on the sea state and weather, water temperature, impending darkness, and the fact that the man was not wearing any survival gear. Estimated survival time in the water was less than the time it would take a helicopter to arrive. In this case a seaplane could have covered the distance to the rescue site faster, but would not have been able to land due to the difficult seas.

The twenty-first search and rescue case that meets the greater than one-hundred-mile-off-the-coast and loss-of-human-life criteria occurs in June 1995. An 800-foot oil tanker from Texas reported that a Honduran crew member fell twenty-four feet to the deck and sustained numerous injuries. The ship was more than four hundred miles off the Texas Coast operating in light winds and calm seas. Based on reports coming from the ship, the Coast Guard launched a rescue helicopter. In order to make the distance the aircraft stopped and refueled on a oil rig enroute. Five and one-half hours after notification, the search and rescue helicopter arrived on scene. After hoisting the victim aboard, the aircraft commander reported that the victim had been dead for quite some time.

No doubt, in this case a seaplane could have arrived at the scene less than in one-half of the time required for a helicopter, not requiring any refueling enroute. However, judging from the aircraft commanders report on the condition of the victim, it is questionable whether the outcome would have been any different.

Case twenty-two involves the electrocution of an Indonesian crewman aboard a freighter more than three hundred miles off the East Coast of Georgia. Though the crew began CPR as soon as they found the victim, he was reported to be cold, showing no vital signs. Thirty-five minutes later the crew reported they had stopped CPR. Based on the crew's reports and the distance involved, no search and rescue flight was initiated.

The complete detailed records for cases twenty-three through twenty-five are missing from the Atlantic area files; only records of the initial notification exist. What is known is all three cases occurred more than three hundred miles off shore and a life was lost after the Coast Guard was asked for help in each case. Two cases involved a man overboard and one case occurred when two vessels collided at sea. However, because the severity of injuries, the weather, sea conditions, time of day, or some other factor affecting the likelihood of success, a rescue mission was not attempted. It is difficult to estimate if a seaplane might have beneficial in these cases. However, if a decision was made not to launch a rescue at all, it is unlikely that any rescue asset would have made a difference in these cases.

<u>District Seventeen</u>

The Seventeenth Coast Guard District's headquarters is in Juneau, Alaska, and has responsibility for all Alaskan waters. Four cases meet the search criteria in the Seventeenth District.

The twenty-sixth case occurs in August 1993. A 100-foot fishing vessel out in the Bearing Sea radioed an American crewman had been seriously injured when he was knocked to the deck by some commercial fishing rigging. The victim was reported to have a possible broken back and a punctured lung. No helicopter was within range of the vessel, and the nearest ship, by chance a Coast Guard cutter, was one hundred twenty miles away. The fishing vessel proceeded at best speed towards shore and the nearest medical facilities, while the cutter plotted a course to intercept the boat enroute. It was estimated that it would be twelve hours before the fishing vessel reached medical assistance. Unfortunately, the patient died during the trip.

While the Bearing Sea is often a formidable body of water, it was summertime and the weather was good. Light winds and a sea swell of only two feet were reported at the time of the accident.

In this case a seaplane may have been able to recover the victim before he died. Another possibility would be the seaplane could have brought life saving equipment specifically for this medical emergency and a physician out to the fishing vessel.

Case number twenty-seven involves a cruise ship 150 miles away from Sitka, Alaska. In September 1995, an eighty-year-old passenger suffered an aortic aneurysm on the way to Anchorage. The weather was reported as clear, wind of fifteen miles per hour, and seas of three-to-five-feet. The ship's doctor tended to the man while the ship called for help. Based on the ship doctor's recommendation, a search and rescue helicopter was launched to fly the patient to the hospital in Juneau. Two hours elapsed from the time the initial call came in to the time the helicopter landed aboard the cruise liner. Unfortunately, the patient died before he was transferred to the helicopter.

In this case a seaplane might have reduced the time of flight to the cruise ship. However, the victim was already under a doctor's care aboard ship. The only thing that might have saved this man's life would have been the availability of the type of equipment in a hospital emergency room and, most likely, a cardiologist. It is possible that a seaplane could have reached the cruise ship, loaded the patient, and returned to Juneau in less than two hours. However, from the airport the victim would have to be driven to the hospital, negating much of the time saved. A second possibility would have been to fly the emergency room equipment and a doctor out to the ship.

Case twenty-eight occurs in September 1995 in the Gulf of Alaska. A Philippine crewman abroad a 700-foot Dutch cargo ship lapsed into unconsciousness after two days of continuous stomach pains. The crew reported that he had a weak pulse and he was breathing with difficulty. Due to the location of the ship, it took over twenty hours of steaming to bring it into search and rescue helicopter range. Weather at the time of the incident was fair seas were

six-to-eight-feet, and the wind was twenty miles per hour. The Coast Guard station in Kodiak, Alaska, launched their search and rescue helicopter in order to rendezvous with the cargo ship 150 miles out from shore. Unfortunately, while the helicopter was in route, the patient died.

In this case a seaplane could have easily reached the ship and returned to medical help before the man expired. While the reported sea state would have made an open-ocean landing difficult, it was well within the abilities of a modern-day amphibian.

The twenty-ninth case also occurs in the Gulf of Alaska. This time, however, it is January 1995. A 106-foot crabbing boat from Seattle is reported capsized in terrible weather. The seas are twenty feet with winds approaching fifty miles per hour. The water temperature is thirty-five degrees, and the air temperature is thirty degrees. Within thirty minutes the fishing boat's sister vessel is on the scene searching. Two other fishing vessels arrive within the hour, and a Coast Guard helicopter from a nearby cutter arrives one hour later.

Two rafts and two bodies are found, but there are no survivors. Survival suits were not worn by either of the victims. Because of the high seas, the helicopter was forced to land and remain aboard the Coast Guard cutter for the remainder of the mishap. The search was abandoned late the next day. In this case, there is no capability a seaplane could have offered to the rescuers. (Note that while this case occurs in what is considered Alaskan waters, the actual case reports originate from the Seattle office. The reason for this is usually the Coast Guard unit sending the majority of the assets to a rescue will do the record keeping and submit the required reports.)

<u>District Fourteen and the Pacific Area District</u>

The Pacific area district represents an amalgamation of Coast Guard areas and has responsibilities along the Gulf of Mexico, California, and out into the Pacific Ocean. Its

headquarters are in Los Angeles, California. District Fourteen has headquarters in Hawaii. Its responsibilities include Hawaiian waters and the Pacific Ocean east toward California.

A total of ten cases occurred in these Pacific waters. Unfortunately, at the time of this writing, the cases occurring in the Southern Pacific Ocean in 1993 have been moved into the National Archives system. For the next two years, the records reside in the Regional Record Center in California. Then, they are moved into the National Archives, assuming the Coast Guard wants to keep them.

Because of the way the records are filed, custody difficulties, time and money constraints, and their physical location in the regional archives office, I was not able to access the eight detailed Coast Guard case files from the Pacific Area and District Fourteen in 1993. However, using the Coast Guard search and rescue MIS database, the general details of these events were constructed. Therefore some of the desired details in cases numbered thirty-two through thirty-nine will be missing from this analysis.

The thirtieth case is a duplication of case twenty-nine. Apparently the Coast Guard Headquarters in Alameda, California, also originated a case number and file on that unsuccessful fishing boat rescue due to their involvement in the event.

The next case involves a disabled fishing vessel that is towed over 100 miles to port by Coast Guard assets. Because the death occurs after the vessel reaches the harbor, this mishap is not considered further in the analysis.

Case thirty-two occurs 240 miles off the California Coast. A Coast Guard helicopter is sent out to rescue a sick crew member on a cargo vessel. The weather and sea state are calm. The victim dies sometime after Coast Guard notification, but before the helicopter can get the victim to medical treatment.

Because it took the helicopter over four hours to get the victim back to medical facilities, it is possible that a seaplane may have moved this person to treatment sooner or brought medical help and equipment out to the scene.

The next case is a death on a commercial vessel off the California Coast caused by personnel error. The nature of this error is unknown, but the death occurred and was confirmed soon enough that the Coast Guard did not launch one of its rescue assets.

Case thirty-four is a death involving sickness after the a Coast Guard rescue was requested. The incident took place 230 miles off the California Coast in very difficult weather, including waves over twelve feet high. The rescue vessel chosen was a ship instead of a helicopter, so it is safe to assume a seaplane would not have been able to negotiate the seas at that scene.

Case thirty-five involves the death of all hands aboard a cargo vessel that is lost in bad weather and difficult sea conditions in the middle of the Pacific Ocean, more than one thousand miles from the nearest possible help. Coast Guard patrol craft searched for two days without locating any survivors or wreckage. Because the mishap summary concluded that all the victims died before Coast Guard notification, it must be assumed that a seaplane would not have been any help in this case.

The next case involved a personal injury or sickness aboard a noncommercial craft more than 200 miles from the nearest Hawaiian Island. This person dies after Coast Guard notification, but before the vessel could come within range of a rescue helicopter. Weather and seas were within seaplane operating parameters, but because of missing details it is difficult to say whether a seaplane might have changed the outcome in this case.

Case thirty-seven is nearly identical to case thirty-six. A person is sick at sea in Hawaiian waters, but out of helicopter rescue range. Before a rescue can be effected, the person

dies. Again, it is difficult to determine the effect of the presence of a seaplane due to sketchy details, though the weather was reported as acceptable.

Case thirty-nine involved the loss of a freighter three hundred miles from Hawaii. Twenty-eight people died when their ship sank in a storm. The Coast Guard is notified before the vessel actually sinks, but due to the weather the first rescue vessel a ship was not on scene until the next day. Though the case summary does not clearly state, there must have been a tremendous storm involved in this situation.

Case thirty-nine is a man overboard three hundred miles from shore. Non-Coast Guard assets search for the man, without success. Because the Coast Guard did not launch a patrol plane to join in the search for some reason, such as water temperature or darkness, any search aircraft including a seaplane would not have benefited the search.

Case Study Summary and Analysis

Speed, time to the rescue site, time on station, cargo capacity relative to a helicopter, and an amphibious capability were the advantages listed earlier in this thesis that a seaplane brings to a maritime search and rescue. Also listed as additional factors affecting an amphibious rescue were weather and sea state, time of day, the physical condition and injuries to the victim, and the type of vessel involved in the search and rescue. The premise of the case analysis was to make only one change to each search-and-rescue event, by making a modern day seaplane available for the Coast Guard initiated search and rescue mission.

It was not surprising that speed and time to the rescue played an important role in at least twelve of the thirty-nine cases analyzed. In nine of the twelve cases, death occurs within approximately two hours. Six cases in particular (1, 4, 8, 10, 26, and 28), show that speed or time to the rescue could make the difference between life and death.

Similarly the added range of a seaplane could have been used to the rescue's advantage in at least five cases (10, 13, 19, 26, 28). Having a rescue craft with a range of more than triple a standard rescue helicopter would change the way decisions are made about open-ocean rescues. Considering the multiple aircraft in case ten or the ocean rescue made by the Navy SEALs described in chapter 1, a seaplane's range would be an important factor in rescue decisions, were it available.

Time on station and time available to search played a relatively minor role in the cases analyzed. Only four of the thirty-nine cases involved a concerted search effort by patrol aircraft and in only one case (7) did the limitations of a helicopter really play into the outcome of the search and rescue. This is due largely to improvements in technology. Radar, satellites, and automatic distress beacons have eliminated much of the need to search for a vessel or personnel in distress. The ability to fly straight to the rescue scene may reduce some of the need for range in rescue aircraft.

Cargo capacity did not adversely affect any of the open-water rescue attempts described here. While there were at least six cases that included more people in the water than a helicopter could carry, the largest number of people a single search and rescue helicopter was actually required to rescue was three. However, that is true only if the capacity to bring back to shore those in need of help is considered.

If instead, one considers the possibility that a seaplane could have carried extensive medical equipment and medical personnel out to the scene of the rescue, a new scenario appears which potentially cuts the time to rescue in half. In each of the eight cases (or more) where speed or range to the rescue site is a significant factor, a seaplane configured as a flying emergency room might have saved a life at the scene of the mishap. Because a rescue helicopter must return a victim to land at half of the speed of a fixed-wing aircraft, the time it takes to get a

person to medical help could be cut by 75 percent by bringing the medical emergency equipment and personnel to the scene in a seaplane.

The amphibious quality of a seaplane did not seem to come into play in the cases analyzed. Three of the rescue cases did involve hoisting a sick (and dying) person up into a flying helicopter. However, it is impossible to tell if the hoisting evolution contributed in any way to the persons' injuries or death.

Nine of the cases analyzed contain weather and sea states too difficult for a modern day seaplane to negotiate. However, only in one of these cases (29) was there a even possibility of a helicopter making a rescue hovering above the waves. For the remainder of cases, a combination of range and weather made rescue very unlikely.

Surprisingly, the cases in Alaskan waters showed potential for successful rescues with a seaplane. The large distances often involved in rescues make a seaplane especially attractive. It is probable that these rescues would be confined to the summer months when the weather is calmer and the majority of commercial fishing traffic occurs.

The onset of night made searching difficult in a number of cases and contributed to the decision to stop the search in at least six of the missions. The ability of a helicopter to search slower over the water at night could be considered an advantage in case seven, though it had no effect on the outcome of the case.

It is difficult to determine the overall impact of the type of vessel on many of the rescue cases. What does seem apparent is if a helicopter rescue hoist was attempted, the weather and seas were adequate for a seaplane to land alongside the vessel. However, it is not known if there would have been problems transferring a victim from the vessel to a seaplane.

New Ideas

The most significant and intriguing idea coming from the case analysis is the idea of a flying ambulance. A seaplane configured as a flying emergency room takes advantage of the seaplane's cargo carrying capacity, its forward speed, and its amphibious, anywhere capability. While there are any number of mobile medical craft, the idea of emergency room type care at the scene of an ocean rescue has not been considered previously.

Data Insufficiencies

It must be acknowledged that the details available on cases thirty-three through thirty-nine were poor. However, I do not believe that fact skewed or affected my case study summary. The general trends were already apparent. Additionally, there was enough detail to confirm that there was no unique situation or requirement in the Pacific rescue cases.

Case Reference Numbers

Appendix D is a list of the search and rescue SITREP numbers assigned to the cases from 1993 through 1995 used in this thesis. Each meets the required parameters of location more than one hundred miles at sea and lives lost after Coast Guard notification.

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[1]U.S. Coast Guard Reports are normally permanently filed in the National Archives for seven years. However they are currently being held in National Archive Regional offices around the country and then being discarded.

CHAPTER 5

CONCLUSION

Topics for Further Study

As stated at the beginning of this thesis, today's budget realities in the U.S. make good decisions about equipment critical to future successes. The importance of speed, cargo capacity and flexibility should be given great consideration in future rescue platforms.

While it is doubtful that the Coast Guard would be able to operate a number of seaplanes just for search and rescue, other options are on the horizon. The *V-22 Osprey* program is one such option. While it is expensive, other service buys could lower overall purchase, operation, and maintenance costs. The *V-22* offers speed, range, and increased cargo capacity over current rescue helicopters. The ability to hover offers additional mission flexibility. While there is no plan to build an Osprey with a full amphibious boat hull at the present time, the Coast Guard might begin to explore this concept.

Wing-in-ground effect technology offers another potentially fast, flexible rescue platform with almost unlimited cargo capacity. While the U.S. seems to have largely ignored this unique approach to transportation, recent developments by the Russians and Chinese indicate another look would be worthwhile.

Finally, this thesis only addresses search and rescue cases out in the open ocean. Investigating water rescues less than 100 miles off the coast of the U.S. represents a significantly larger body of evidence and a more complex set of variables.

Safety at Sea

As increasing world trade indicates continued growth in commercial use of the high seas, the number of emergencies on the open ocean is likely to increase. Certainly maritime safety has improved over the last few decades. Satellite technologies have improved communications as well as weather prediction, helping maritime traffic avoid dangers that were once just part of the job. Although the U.S. Coast Guard has a comprehensive safety program for American vessels, a large portion of shipping in U.S. waters is foreign flagged, and not bound by Coast Guard safety standards.

In fact, only three of the cases reviewed in chapter 4 contain a death that can be directly attributed to vessel safety. By far the largest cause of death can be categorized as human error. There were sixteen cases of falls, mistakes, and man overboard. Sickness and heart attacks accounted for twelve deaths and weather was the direct contributor to death in six cases. In total, almost 90 percent of the injuries leading to death in the cases studied were caused by sickness, human error, or weather.

It is unlikely that these types of deaths can be eliminated from maritime operations regardless of how well the U.S. Coast Guard is funded. So in combination with greater maritime traffic, injury and death (related to sickness, human error, and weather) can be expected to rise as maritime traffic continues to grow. Will the helicopters, ships, and patrol planes of current search and rescue forces adequately met the future SAR needs in the U.S.?

Conclusion

Is the search and rescue seaplane a flying dinosaur, or does it offer a method to save additional lives in open ocean rescue scenarios? Was the Navy SEAL's rescue described in chapter 1 a unique situation or does it demonstrate a need for an additional method of open ocean rescue?

Chapter 1 of this thesis describes a history of successful search and rescues by seaplanes. Granted, before World War II a seaplane was all that was available in many cases, but the successful employment of amphibians cannot be argued.

The modern seaplane, exemplified by the Japanese Model US-1, is significantly more capable than the seaplanes eliminated from Navy and Coast Guard inventories in 1960. The ability to land at one-third the airspeed required of older seaplanes and negotiate double the sea state makes the modern day seaplane a very capable search and rescue tool. My methodology to test whether a modern seaplane would make a difference in current search and rescue missions in the U.S. was to examine a set of current search and rescue cases and examine the differences a seaplane would have made if any in each case.

Using the set of U.S. Coast Guard cases from 1993 through 1995 involving a death more the 100 miles out in the ocean, some substantive observations can be made. Had a seaplane been within rescue range in seven of the cases described in chapter 4 (4, 8, 10, 13, 26, 27, 28), there is a strong possibility the victims' lives could have been saved. Seven additional cases (1, 16, 19, 21, 32, 36, 37) offer a smaller but still significant possibility of saving an additional life lost to current search and rescue methods.

Returning to the research question; would additional lives be saved if U.S. search-and-rescue forces had a modern-day amphibious aircraft at their disposal? The answer to that question is most certainly, yes. It is also very likely that their are many more rescue cases similar to the situations studied here less than 100 miles off the coast, but many hundreds of miles from the nearest Coast Guard helicopter rescue station. So the number of potential additional lives saved could be significantly larger.

Cost Justification Difficulties

It is different to justify on a cost basis the U.S. Coast Guard operating a squadron of modern day seaplanes. A likely operational scheme would include the Coast Guard operating amphibians out of Miami, Norfolk, Corpus Christi, Los Angeles, Seattle, and Anchorage in the summer months. Small maintenance teams would deploy with the aircraft and major work would be accomplished through rotation of airframes back to a main maintenance facility.

The cost of this operation would likely be prohibitive. Modern amphibious aircraft similar to the Japanese US-1 would likely be between fifty and one hundred million dollars per copy. The cost of a squadron might approach the billion-dollar mark. Overhead, training and personnel would all have to be added in to the question.

My research showed the potential of saving an additional 2-4 lives annually in open-ocean search and rescues. However, there is no accepted way to put a value on these lives. One could argue that a human life is worth any cost, but then this program would have to be weighed against other worthy government humanitarian assistance programs. Others have tried to use lifetime earnings as a measure of the value of human life. The 1992 U.S. Census Bureau Population Survey estimated lifetime earnings for college graduates at $1,420,000 and high school graduates at $820,000. Using this approach, at least 50 additional lives per year would have to be saved to justify a ten-plane squadron over a 15-year period. A third approach would be to put no value on human life and instead base decisions on the capability of the equipment, similar to the Defense Department's current capabilities based procurement strategy.

Final Thoughts

Regardless of how you attach importance to additional lives saved in search and rescue missions, some important ideas become clear when reviewing the open ocean search and rescue

cases of the last few years. First and foremost, speed is critical. Speed is needed to cover greater distances and shorten the time from notification to the delivery of medical assistance to a victim.

Increased cargo capacity offers the ability to dramatically shorten the time to medial assistance. By bringing the medics and emergency equipment to the site of the emergency, the time for a medical rescue could be reduced by as much as 75 percent over current helicopter lifts to shore-based hospitals.

Although the case studies did not clearly show need for a pure amphibious capability, the flexibility of an amphibious aircraft cannot be overlooked. There is no such thing as a standard rescue requiring a standard rescue craft. Medical emergencies at sea, refugees problems, and accidents caused by human error will continue to be extremely varied. The seaplane offers mission flexibility and versatility not found in any other sea or aircraft.

APPENDIX A

APPROXIMATE SEA STATE EQUIVALENTS

Appendix A provides a basic descriptive tool for the kind of sea conditions an amphibious aircraft might encounter in the open ocean. Values given are averaged from a number of sources and can only approximate a complex ocean wave pattern. For example, in water considered Sea State Three, the wind would be anywhere from nine to nineteen knots, wave lengths anywhere from forty to one hundred fifty feet, and wave heights from five to fifteen feet.[1]

Sea State Rating	2	3	4	5
Wind Velocity (KTS)	9	15	19	25
Req'd Wind Duration (HRS)	5	20	23	27
Wave Length (FT)	40	80	150	220
Wave Height(FT)	5	10	15	20
Wave Velocity (KTS)	8	12	16	20
Fetch* (MILES)	50	100	200	250

Fetch is the required amount of open ocean the wind must blow over to achieve these wave figures. This table applies only to locally produced waves and does not consider waves originating elsewhere (swell). All values are approximate.

[1]Main sources are the Canadair Corporation's CL-415 *Rough Water Operations* Memo and *Aero-marine Design and Flying Qualities of Floatplanes and Flying Boats* by Darrol Stinton.

APPENDIX B

SAR RESCUE VEHICLE CAPABILITY SUMMARY[1]

	Unrefueled Range (mi.)	Max Cruise Speed (mph)	Cargo Load (lb.)	Amphibious	Sea State
Helicopter ex., SH-60	300	150	4000	N	(hover)
Patrol Type Aircraft (Prop) ex., P-3	2000+	400+	10000+	N	N/A
Patrol Type Aircraft (Jet) ex., Saberliner	3000+	550+	2000+	N	N/A
SAR-Capable ship	1500+	20+	varies	N	5+
Seaplane US-1A	2300	300	10000	Y	3+
Seaplane CL-415	1300	210	9000	Y	3

[1]Janes's All the World's Aircraft, Sentinel House, (Coulsdon, Surrey) 1996.

APPENDIX C

Search-and-Rescue Situation Report Format

Date, Time
Originator
Addressees

Classification

1. Situation: contains what happened, how the Coast Guard was notified, and a narrative of the events as the C.G. responded. This portion of the report also contains the weather and sea-state information.

2. Action taken by the Coast Guard: contains a time line of C.G. actions from initial notification through case resolution.

3. Future Plans and Recommendations.

4. Amplifying Information.

5. Case status includes summary of flight time and time on station.

APPENDIX D

IDENTIFICATION OF COAST GUARD CASES USED IN THIS THESIS

Seventh District	93SU711070384, 93SU711071228, 9407MULTI0789, 9507MULTI0608, 9507MULTI0991, 9507MULTI1084 (Thesis Cases 1-6)
Eighth District	9308MULTI0531, 9508MULTI0310 (Thesis Cases 7, 8)
Thirteenth District	93SU711130040, 9413MULTI0153, 9513MULTI0610 (Thesis Cases 9-11)
Fourteenth District	93SU711140013, 93SU711140235, 93SU761800011, 9314MULTI0015, 9314MULTI0016, 9314MULTI0179 (Thesis Cases 30-35)
Seventeenth District	93SU711170205, 9517MULTI0235, 95SU202800197 (Thesis Cases 27-29)
Atlantic Area	93SU751200065, 93SU751200304, 93SU75120335, 9320MULTI7182, 9320MULTI7212, 94SU751200085, 94SU751200128, 94SU751200150, 95SU711070482, 95SU751200111, 95SU751200272, 95MULTI7059, 95MULTI7251, 95MULTI7303 (Thesis Cases 12-25)
Pacific Area	93SU751500014, 932MULTI7215, 9421MULTI8052, 9521MULTI8023 (Thesis Cases 36-39)

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